HANDBOOK OF STERILIZATION PROCEDURES

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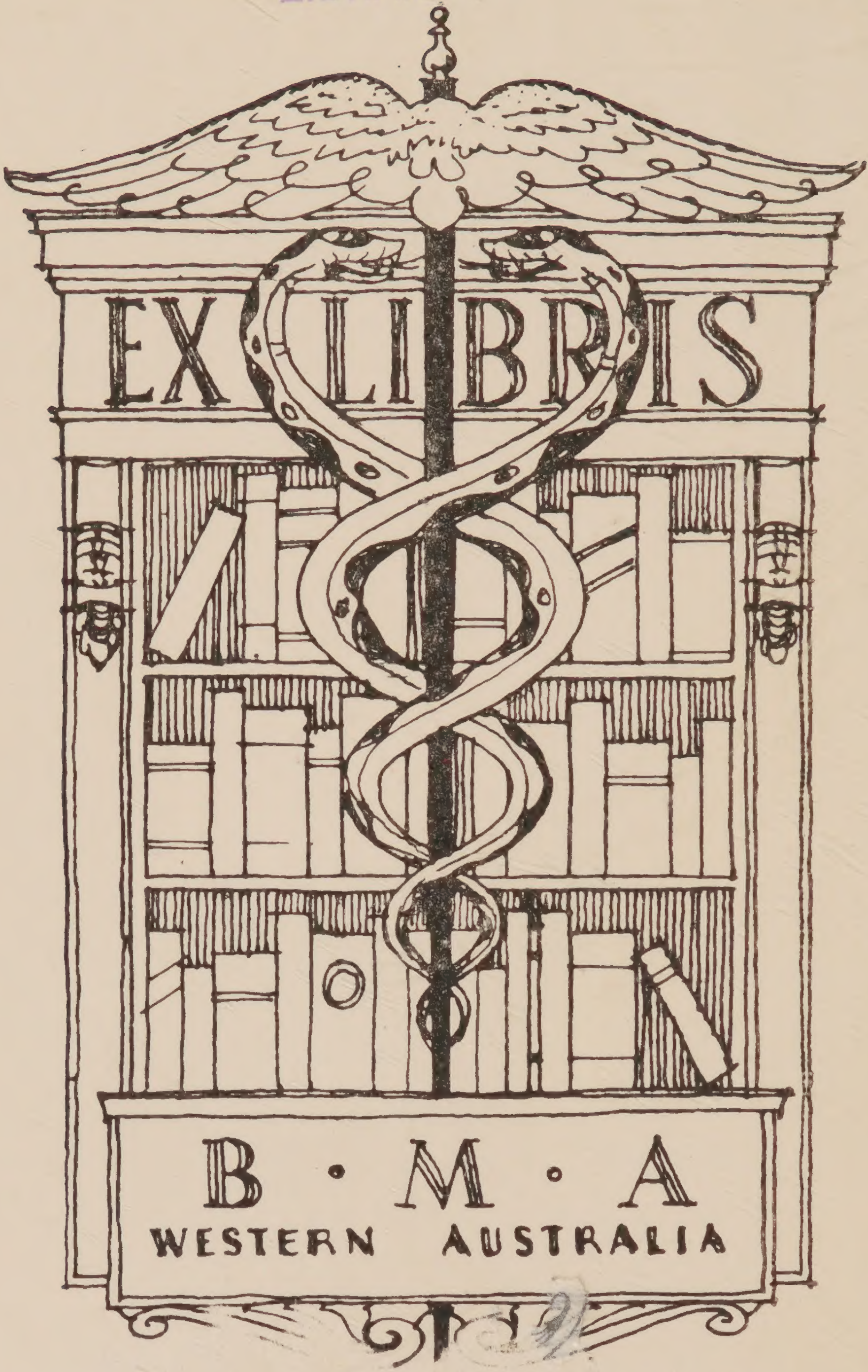

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HANDBOOK OF STERILIZATION PROCEDURES

(Recommended techniques for use in Queensland public hospitals.)

Issued by Direction of
The Honourable the Minister for
Health and Home Affairs.
1953.

A. H. Tucker, Government Printer, Brisbane.

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Foreword.

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The occurrence in Queensland of several cases of neo-natal and post-operative infections, such as tetanus and gas gangrene, caused by spore-forming organisms, directed attention to the methods of sterilization in use in Queensland hospitals—both public and private.

Sterilization techniques were found to vary from hospital to hospital. A few hospitals used sterilization procedures of undoubted efficiency; some hospitals used good methods for some procedures only to fall down on others, whilst other hospitals used sterilization techniques which were uniformly unsafe.

Sterilization procedures were sometimes performed by operators, such as trainee nurses, who did not understand the principles of the procedure. Only too often it was obvious that personnel in charge of sterilization procedures did not understand that spore-bearing bacteria are extremely difficult to kill, and had no idea of the temperature and exposure necessary to produce sterility in various items used constantly by hospitals.

Some hospitals did not possess autoclaves; others had autoclaves which were unsafe; others again had efficient autoclaves which were used in an inefficient manner. In general, undue reliance was found to be placed in sterilization by chemicals in spite of the fact that chemical disinfectants rarely produce sterility. Thus, syringes and cutting instruments were commonly stored in disinfectant and merely rinsed in water before use.

Whilst it was evident that sterilization methods in many Queensland hospitals were unsatisfactory, it is known that similar conditions exist in other Australian States. The rarity of infection with pathogenic spore-forming organisms is due not so much to the efficiency of the sterilization techniques adopted, as to the comparative rarity of their natural occurrence in articles brought into contact with human tissues. But these infections can and do occur occasionally in any hospital—tetanus bacilli are commonly found on wooden hospital floors, and they also occur naturally in other material which may contaminate wounds.

Heavy expenditure has been incurred in replacing or repairing inefficient hospital autoclaves in Queensland, but the price of safety cannot be assessed in money. Any patient undergoing a surgical operation in a modern hospital has a right to expect that his life will not be endangered by accidental contamination of the operation wound.

The methods outlined in this handbook have been adopted after much consideration. In some instances, experiments were performed to develop a safe technique.

Sometimes more than one procedure is recommended for the sterilization of certain items, but for many items no alternative procedure can be recommended.

It is hoped that hospitals, by adopting the techniques laid down in this book, may reduce the incidence of wound infections.

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CHAPTER 1.

HISTORY OF HEAT STERILIZATION.

To most people living in the twentieth century, it may sound incredible that one hundred years ago violent controversies centred around the origin of infection. A Dutchman, Antonj van Leeuwenhoek, had seen and described bacteria, or, as he called them, "animalcules," towards the end of the seventeenth century, but their significance in causing infection and disease was not understood. Most educated people believed that the bacteria known to be present in infection and in putrefactive processes arose from spontaneous generation within the infected substances. Between 1860 and 1862, the classical researches of Pasteur on fermentation and on bacteria in air caused a sensation in scientific circles. Against much opposition, the belief that bacteria produced disease gained ground. About 1875 the investigations of Pasteur in France and Koch in Germany on anthrax began the era of the germ theory of disease, which to-day has universal acceptance.

It is probable that the theory of spontaneous generation would have been accepted much earlier had it not been for the unsuspected presence of bacterial spores which are extremely difficult to kill. The presence of spores resulted in growth in infusions that had previously been boiled and that therefore had been regarded as sterile. Tyndall, for instance, found that infusions prepared at the Royal Gardens at Kew which could be rendered sterile by boiling for five minutes could not be sterilized by boiling for up to five hours when prepared at the laboratory of the Royal Institution in London. The reason was that the floor and air of the London laboratory contained resistant spores from bacilli present in hay. Spores were not recognised until 1877, when Cohn described the spores of *Bacillus subtilis*.

The practice of heating liquids and other objects to temperatures of 115°-120°C seems to have begun when Pasteur and Chamberland attempted to repeat experiments of Bastian, a London physician, who claimed that he was able to create life from non-living matter. Chamberland (1851-1908) is credited with perfecting the sterilizing instrument known as the autoclave, though some writers give the honour to Lucas-Championière, a surgeon who collaborated with Pasteur. Autoclaves were manufactured and sold in Paris about 1884. Koch and Wolffhügel developed the technique of sterilization with hot air in 1881.

In 1880 Gustav Neuber introduced the concept of aseptic surgery by making instruments and dressings sterile, and by insisting on caps and gowns in the operating theatre. In the next few years, the effect on bacteria of the various types of heat sterilizer was investigated by workers in Koch's laboratory and before 1890 Von Esmarch had introduced sterile dressings and had studied the effect of superheated steam on sterilization. In 1891 Schimmelbusch advocated the use of sterilized nail brushes to check the spread of sepsis. He added 1% sodium carbonate to water to increase its germicidal activity. Halsted introduced rubber gloves in 1889, while Flugge and von Mikulicz-Radecki studied the bacteriology of the air and introduced masks in 1896.

During this period other pioneers had been active in introducing to modern surgery the principles of the dry operative field, the sterile buried suture, effective haemostasis, and the antiseptic effect of various chemical compounds. Many of the developments of present day aseptic surgery are due to von Bergmann, and from von Bergmann's clinic in 1891 came Schimmelbusch's book "The Aseptic Treatment of Wounds" which spread throughout the world the aseptic techniques developed in Berlin.

In a lecture delivered to the Paris Academy of Medicine in 1878, Louis Pasteur declared:—

> "If I had the honour of being a surgeon, impressed as I am with the dangers to which the patient is exposed by the microbes present over the surface of all objects, particularly in hospitals, not only would I use none but perfectly clean instruments but after having cleaned my hands with the greatest care and subjected them to a rapid flaming, I would use only lint, bandages and sponges previously exposed to a temperature of 140°C. to 150°C."

This remarkably prophetic declaration was ignored for many years, until Lister's antiseptic surgery and the aseptic techniques of the German school became widely known. Lister, regarded as the father of modern surgery, freely acknowledged his debt to Pasteur in having "demonstrated the truth of the germ theory and thus the principle upon which alone antiseptic surgery could be carried out."

Most of the procedures advocated in this booklet were thus developed over fifty years ago, and it is rather surprising to find that they have apparently been taken for granted in our medical and nursing teachings, so that it is now necessary to recapitulate them. As Carl Walter states in his ''Aseptic Treatment of Wounds'' (1948):—

> ''Surgical technique was the fascinating pursuit and as subordinates assumed the responsibility for aseptic technique many of the earlier lessons were either forgotten or applied in a garbled form. The development of the steam sterilizer is illustrative. The detrimental effect of air in the sterilizer, the hazard of super heating, the protection afforded bacteria by oil and grease, the advantage of gravity air clearance, the influence of sterilizer design on efficiency, the necessity of measuring the bactericidal power of steam by taking its temperature, were recognised in scattered clinics. Some surgeons boasted ideal equipment, but visitors to their amphitheatres came to see operative procedures and returned home to improvise equipment and technique to enable them to do the surgery they had witnessed. The important details of the steam sterilizer were forgotten, to be rediscovered during the past twenty years.''

The object of this booklet is to remind doctors and nurses that these principles cannot be neglected, if sterilization is to be achieved. In the absence of bacteriologists in the majority of hospitals, doctors must again interest themselves in supervising sterilization procedures.

CHAPTER 2.

METHODS OF STERILIZATION.

Brief Review.

Keeping in mind that it is necessary to kill all pathogenic organisms, no matter how resistent, before an article can be called sterile, the various methods of sterilizing hospital supplies are enumerated below:—

(*a*) Sterilization by Moist Heat.

(*b*) Sterilization by Dry Heat.

(*c*) Sterilization by Chemical Substances.

(*d*) Sterilization by Physical Agents.

(*e*) Sterilization by Filtration.

It is advantageous for the operator of a sterilization unit to understand the principles, together with the advantages and disadvantages, of each method.

(a) Sterilization by Moist Heat.

The chief advantage of moist heat over dry heat is that the former is lethal to bacteria at a lower temperature. It is generally conceded that death of bacteria at relatively low temperatures occurs by coagulation of protein and that moisture is necessary for this process. To illustrate the importance of moisture in coagulating protein at various temperatures, take the example of egg albumen subjected to heat. If the egg albumen solution contains 50% of water, it coagulates at 56°C (113°F); if it contains 6% of water, coagulation occurs at 145°C (293°F), whilst if it contains no water, coagulation occurs at the relatively high temperature of 160°C (320°F).

Boiling water and steam under pressure are the common sources of moist heat. Boiling water has definite advantages—it can be prepared easily and is universally available. Its great limitations are first that certain articles (e.g., powders, oils, or substances soluble in water) cannot be placed in boiling water, and secondly, that the temperature of boiling water, at atmospheric pressure, can never exceed 100°C, which is inadequate for the destruction of certain spores, even if exposed to boiling for several hours. This latter disadvantage can be overcome to a great extent by the addition of alkali or acid to the water, provided the articles being sterilized are not damaged by these substances.

Steam under pressure, as provided by an efficient autoclave, has a higher temperature than boiling water, yet still contains moisture. It is ideal for the sterilization of textiles, such as operating theatre packs.

The disadvantages of steam under pressure are that it is corrosive to certain metals, that if the articles are porous they are completely wet, and that, if they are not porous, the advantages of moist heat are lost because it is possible to expose only the exterior surfaces of the article to its influence. Furthermore, anhydrous oils, greases, and powders cannot be permeated by steam.

However, methods have been devised to dry articles sterilized by steam—the commonest being to subject the load to a partial vacuum after sterilization, thereby enabling steam to escape rapidly from the load.

Although steam penetrates porous articles rapidly, it should be noted carefully that some time elapses before the centre of the article attains the temperature registered in the chamber of the autoclave.

This time lag, which varies with the size and density of the load, and its arrangement in the autoclave, must be taken into consideration when laying down exposure periods. This subject is dealt with in greater detail in a later chapter.

(b) Sterilization by Dry Heat.

Dry heat or hot-air sterilization is less dependable than sterilization in an efficient autoclave, because it is difficult to ensure an even temperature in all parts of the hot-air oven. Most hot-air ovens have the heating element at the bottom, and the heated air circulates by gravity convection through the chamber of the oven. The speed with which the air circulates depends on the adjustment of the air vent and on the opposition to convection caused by corners or by the nature of the load. Modern hot-air ovens are fitted with a fan or turbo blower to ensure even distribution of heat, but an oven not so fitted is apt to have "cold spots."

The lethal action of dry heat is probably due to dehydration of the bacteria, so that death occurs before the temperature necessary to cause coagulation is reached. This drying causes irreversible oxidative changes inside the bacterial cell. It is worth noting also that dry heat kills more slowly than moist heat. Whereas exposure of spores of *Clostridium tetani* to moist heat at 121°C (250°F), will destroy them in one minute, at least fifteen minutes is required for dry heat at 140°C (284°F) to produce the same result. Whereas a temperature of 120°C (248°F) is required for saturated steam in an autoclave, a temperature of 160°C (320°F) is required for hot air. In addition, the exposure time must be prolonged.

Nevertheless, hot air sterilization is the method of choice for articles which do not withstand corrosion, and for substances which are anhydrous. Thus needles, syringes, cutting instruments, powders, waxes, and oils are best sterilized by hot air.

Like moist heat, dry heat is much less effective if organisms are buried beneath a coating of grease or organic matter. For example, if instruments are clean, they can be sterilized by dry heat at 160°C in one hour, whereas greasy or dirty instruments require exposure for at least four hours.

Close regulation of temperature is important in hot-air sterilization to avoid over exposure or under exposure, and possible deterioration of heat sensitive items. Always place the load in the cold oven, in such a way that air can still circulate freely, then turn on the heat and set the thermostat to maintain the required temperature. Time the exposure from the moment when the oven thermometer records 160°C (320°F). Avoid opening the door during the exposure period, and remove the load only when the oven has cooled off.

(c) Sterilization by Chemical Substances.

A chemical compound capable of killing bacteria is known as a disinfectant or germicide. Bacterial death depends on the concentration of the disinfectant and the time during which it acts. Numerous chemical substances will kill bacteria, provided the concentration of the substance and the time during which it acts are appropriate. However, the number of substances that will kill quickly in low concentrations is quite limited. To be effective the chemical must be brought into contact with the bacteria present in the solution or in the tissues, and then the chemical must be able to act on the cell structure or on the vital functions of the bacterial cell, in such a way that death ensues. Many factors, such as the presence of organic matter, may interfere with this process, and even when contact of disinfectant with bacteria is achieved, bacteria existing in clumps may escape destruction. In addition, some disinfectants appear merely to coat the organism with a film of disinfectant, so that bacterial multiplication is inhibited but the bacteria themselves do not perish. This inhibiting action, which is more marked in some disinfectants than in others, can give misleading results when assessing the efficiency of disinfectants by laboratory tests.

The great disadvantages of disinfectants are that few will kill all bacteria present in a wound (for instance) without impairing the vitality of the tissues, and that fewer still have a lethal action on bacterial spores. This failure of most disinfectants to kill spores seriously limits their use in reliable sterilization procedures.

Although disinfectants have a wide use in hospitals, it is felt that too much trust is placed in them by hospital personnel. They are expected to kill all bacteria, they are frequently applied as if they acted instantaneously, and they are often used to cover up defects in the aseptic or ''no touch'' technique. Hence they are used to ''sterilize'' instruments, to clean wounds, to ''sterilize'' hands without preliminary washing, and to ''sterilize'' material rich in organic matter. Unless it is known that the disinfectant used is specially adapted for the particular use to which it is put, too much reliance should not be placed on its action.

In suitable circumstances, a good disinfectant will destroy vegetative or non-sporing bacteria, but the same substance may be completely ineffective against spores. In other words, it is relatively easy for a disinfectant to kill bacteria; it is very difficult for the same chemical to kill resistant spores—disinfection is easy, sterilization is difficult.

(d) Sterilization by Filtration.

Many types of filter have been devised to prevent the entry of bacteria, but sterilization by filtration is little used in modern hospitals, except for the preparation of fluids or solutions (e.g., serum, antibiotic solutions) which cannot be sterilized by heat. Attempts are sometimes made to purify the air of wards and operating theatres by passing it through filters made of cotton wool, felt, glass wool, or steel wool. These filters are not highly efficient, and, unless maintained properly, are a menace in that they can mislead the unwary into believing the air is free of bacteria. If air must be free of organisms and dust, it is advisable to heat the air or to use electrostatic precipitation.

(e) Sterilization by Physical Agents.

Physical agents used to disinfect (rather than sterilize), include sunlight, ultra-violet light, drying, and high-frequency sound waves.

The short wave rays of sunlight—these include violet and ultra-violet—have a definite bactericidal action. Two hours' exposure to direct sunlight, will kill the typhoid bacillus, whilst tubercle bacilli, if not covered by mucous, are killed within a few days. The lethal effects of sunlight are due to a combination of heat, ultra-violet radiation, and drying. Cotton goods properly laundered and hung in the sunshine are almost free of bacteria. Although the action of sunlight is uncertain, rooms and articles that have been contaminated by bacteria are benefited by frequent exposure to the sun.

Ultra-violet radiation is now produced on a commercial scale for the disinfection of food premises, poultry sheds, and to reduce the bacterial population in hospital wards and theatres. Ultra-violet lamps are useful for this purpose, but their installation should be regarded as a luxury unless every other precaution is already being taken to reduce the number of bacteria in the air of theatres and wards. Oiling of floors and blankets, care in bed making, and a rigid technique of dressing wounds and of nursing infectious diseases are more important than reliance on ultra-violet radiation alone.

Heat is, of course, a physical agent, and its use for purposes of sterilization forms the basis of all modern techniques.

CHAPTER 3.

TESTING OF AUTOCLAVES.

In order to ascertain the efficiency of autoclaves in general use, several were tested in Queensland hospitals by the Committee.

The technique was to place a thermocouple in a bundle of dressings, of the size routinely used in that particular autoclave. The thermocouple is particularly valuable because it records not only the temperature but also the time taken to reach that temperature. In other words, the time lag between the temperature of the steam and the temperature inside the package can be readily ascertained.

In addition, a maximum recording mercury thermometer was included in the bundle to check the accuracy of the thermocouple. Another maximum recording thermometer was placed on top of the load and tubes of benzoic acid (melting point 120°C) were scattered through the load.

Tests gave interesting results and several results are incorporated in Figure 1.

Autoclave A was a newly-developed electrically-heated model, and is strikingly efficient. A thermocouple inside the chamber recorded 120°C within four minutes of turning steam into the chamber, and reached a maximum of 126°C in seven minutes. That temperature was maintained throughout the test.

Autoclave B had steam laid on, and steam circulated constantly through the jacket. When steam at 20-lb. pressure was admitted into the chamber the temperature rose to 118°C in four minutes and to 120°C in five minutes.

Autoclave C, an electrically-heated model, had insufficient heat input. The temperature in the chamber did not reach 120°C until about 30 minutes after admitting steam.

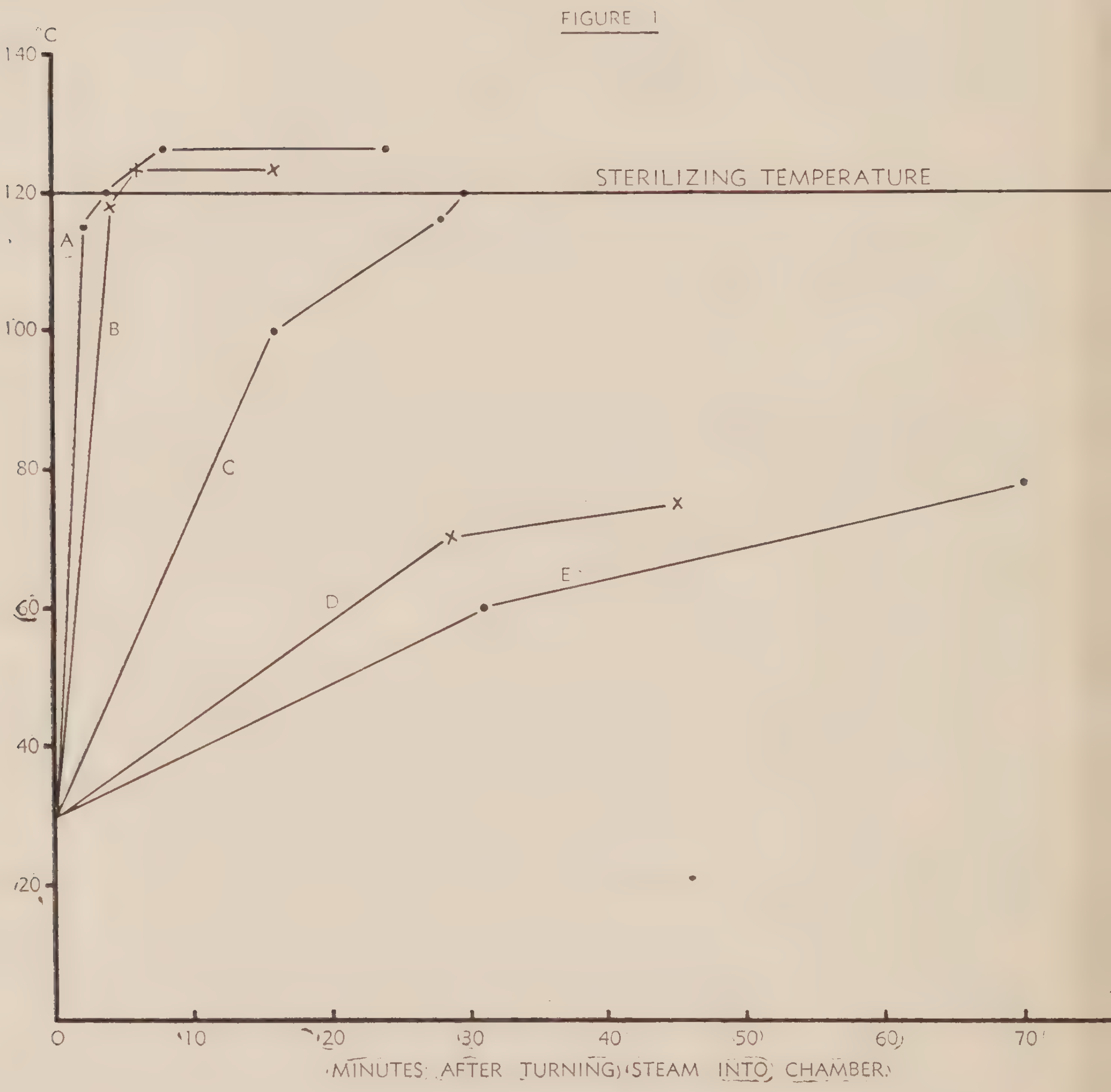

FIGURE 1.

Showing the wide variations in performance of five autoclaves tested in Brisbane. Temperatures recorded are temperatures inside chamber, but not inside bundles; except for Autoclave E.

Autoclave D was overloaded with bundles and was inef- ficiently heated. After 45 minutes the temperature had reache only 75°C.

Autoclave E also showed deficient heating. After 70 minute the temperature was only 78°C.

The lesson to be learned from these tests is that unless the temperature of steam in the outlet is known, sterilization must always be a matter of guess work. Pressure alone is not a guide. An accurate thermometer (preferably fitted into the steam outlet close to the chamber) is essential, so that at all times the operator may know the temperature reached inside the autoclave.

Methods of Testing Autoclaves.

An autoclave fitted with an accurate thermometer does not require testing, but users of autoclaves not so equipped can test the temperature of the chamber in three ways.

(*a*) Capillary tubes containing benzoic acid (B.P.) which has a melting point of 120°C-122°C, and a little methylene blue can be obtained by public hospitals, on demand, from the Department of Health and Home Affairs. One tube is placed in a bundle on the bottom of the load at a point furthest from the inlet, and another in a bundle on top of the load. After the usual autoclaving process, the benzoic acid should be found to have melted, become uniformly blue and to have run to one end of the tube, indicating that the temperature of 120°C-122°C has been reached. These tubes will not indicate the time the load has been kept at that temperature, but for practical purposes they are excellent.

(*b*) An accurate maximum recording thermometer can be wrapped in a test bundle in the load. This, again, will indicate the temperature reached, but will not indicate the time the load was kept at that temperature.

(*c*) With a thermocouple and micro-galvanometer the temperature can be ascertained at any time during the autoclaving process. The thermocouple is placed in a bundle, usually side by side with a maximum recording thermometer, and wires lead out under the door of the autoclave to be connected to a galvanometer. Instant readings, accurate to at least 1°C, can be made at any time. The instrument is invaluable for determining the lag periods which must elapse before the temperature in large bundles approximates to that of the steam in the chamber. These potentiometer tests are not generally available to hospitals, as they require a skilled operator.

(*d*) If it is considered desirable to test penetration of bundles by steam, this can be effected quite simply by placing inside a test bundle a small piece of filter paper marked by an indelible pencil. Steam penetration will be shown by a change of colour in the indelible pencil marking.

(*e*) If it is desired to test both temperature and steam penetration, the benzoic acid tube, together with a piece of filter paper marked with indelible pencil, can be placed inside an open test tube and enclosed in the bundle to be tested. The test tube should lie horizontally in the bundle.

(*f*) Commercial temperature indicator preparations are available, but all have the defect of recording only the maximum temperature reached without indicating the time to which the load was exposed at that temperature. Nevertheless, hospitals desiring to purchase commercial test preparations such as the Teller Test Tubes, can do so provided they keep in mind the limitation of the method.

If an autoclave is fitted with a reliable and accurate thermometer it should rarely be necessary to place temperature test tubes in theatre packs, except for the purpose of an occasional check.

CHAPTER 4.

SURGICAL STERILIZATION BY MOIST HEAT.

In aseptic surgery, sterilization of equipment by moist heat from steam under pressure is absolutely essential. This form of sterilization is provided by an efficient autoclave.

Advantages of Moist Heat.—Micro-organisms are destroyed by coagulation of the bacterial protoplasm, and moisture is essential for coagulation at moderate temperatures. Steam contains that moisture, and so it is more efficient than dry heat alone at the same temperature.

Steam under pressure is used rather than atmospheric steam, because it has a higher temperature. Steam at atmospheric pressure will not destroy, in any reasonable time, resistant spores such as those of tetanus and gas-gangrene. Pressure is required solely to attain a sterilizing temperature. Nearly every operator assumes that the pressure of steam is the essential factor in sterilization, and that if correct pressure is indicated on the pressure gauge, an effective temperature in the load will necessarily follow, irrespective of the size and density of the packs, the amount of air in the sterilizing chamber, and the mechanical condition of the autoclave. It is therefore necessary to stress that *pressure itself has nothing to do with the destruction of bacteria. Its only importance is to produce the required temperature.*

How Saturated Steam Works.—The steam used in an autoclave is saturated steam. Steam is an invisible gas, except when it condenses. If water is heated in an enclosed space, such as an autoclave, the pressure of the mixture of air and steam above the water will increase as heat is applied, but the water will not boil as steam cannot escape freely. Instead, the temperature of the steam and water, and the pressure of the steam all continue to rise.

When admitted to the sterilizing chamber, steam condenses at once on any object colder than itself. The latent heat of the steam, liberated on condensation, raises the temperature of the object. As steam condenses the space which it occupied is filled with more steam, and this in turn condenses until the temperature of the cooler object has been raised to that of the surrounding steam, when no more condensation occurs. By this means, steam penetrates quickly into the interior of packages, and heat is distributed with great speed.

Because steam must penetrate the load and displace the air contained therein, the temperature in the centre of a package rises more slowly than the temperature in the chamber. Reference to Figure 10 will show that a varying period must elapse between the time when the chamber temperature reaches 120°C and the time when the temperature inside a bundle attains this figure. This "lag" period, as it is sometimes called, must be kept in mind when determining sterilization times. For instance, a load consisting of small packages, such as gauze packs or gloves, which are properly spaced, will permit quick penetration of steam, and the temperature inside a package will approximate the chamber temperature within a few minutes. On the other hand, thermocouple readings in a bundle of surgical linen weighing 16 pounds showed that a temperature of 120°C (248°F) was not reached until twenty-seven minutes after steam was turned into the chamber, whereas the chamber thermometer recorded this temperature in about three minutes (see Figure 10). The lag was therefore twenty-four minutes. Even with the bundle weighing about nine pounds, which is now advocated as the maximum size, the lag time can be approximately twenty minutes. The lag time depends not only on the weight of the package but on the way it is folded, packed, and placed in the autoclave. Sheets and other items made of fairly thick cotton material must have many folds, and each layer of cloth encountered by the steam delays penetration into the centre. It is interesting to note that thermocouple tests show that if a test tube, lightly stoppered with cotton wool, is placed in the centre of a bundle, the temperature inside the tube rises much more quickly than the temperature on the thermocouple lying between layers of material in approximately the same position in the same bundle. It seems that the rigid tube does not collapse when steam pressure is applied, and interchange of air and steam occurs more freely. Therefore, if any particularly large piece of linen requires sterilization, the folds should be kept open by some rigid material such as wooden or aluminium slats to allow rapid entry of steam to as many surfaces as possible.

The following facts are of great importance:—

(*a*) Steam must have free access to every surface to be sterilized.

(*b*) Steam cannot penetrate into closed metal or glass containers.

(*c*) Steam can penetrate gauze, calico, loose texture paper, such as brown Kraft paper, but materials such as canvas, tightly-woven paper, and cellophane are unsuitable for wrapping packages.

(*d*) Steam is lighter than air, so that it will not readily enter drums, flasks, or other containers, even if open at the top, unless they are inverted or are laid horizontally, so that the contained air can flow out freely.

Temperature required for Sterilization.—During the autoclaving process a temperature must be reached that will kill, within a few minutes, the most resistant pathogenic organisms in any part of the load. When highly resistant strains of spores (such as those of *Clostridium tetani*) are freely exposed to flowing steam, they are killed in five minutes at 240°F, and in approximately one minute at 248°-250°F. In view of the fact that death at 248°F (120°C) is practically instantaneous, this temperature should be regarded as the ideal to attain. In this book, therefore, 248°F (120°C) will be referred to as the sterilizing temperature.

It must be remembered that pathogenic spores are very rarely found in a state where steam can act on them immediately. Spores may be present in solutions, or enclosed in fibres or embedded in organic matter, and under these conditions, steam penetration can be considerably delayed. However, as soon as the temperature in all parts of the load reaches 248°F, exposure at that temperature for a further ten minutes will give a fair margin of safety when the articles to be sterilized are reasonably clean. The time required to reach 120°C in all parts of the load will vary according to the size and density of the individual items comprising the load, but the recommended sterilization times for various types of material quoted later make allowance for this time lag.

When steam is admitted to an autoclave chamber, it mixes with the air. A considerable time often elapses before the mixture is uniform. The presence of air impairs the sterilizing properties of steam in various ways. In the first place, air is twice as heavy as steam at the sterilizing temperature, and if mixture is slow or incomplete, the steam tends to rise to the top, leaving cold pockets of air and steam at the bottom of the autoclave. Secondly, some heat is extracted from the steam to heat the relatively cool air, thereby lowering the temperature in the chamber. Thirdly, reference has been made previously to the ability of steam to permeate and heat porous substances by the process of condensation and release of latent heat. If air is mixed with the steam, only the steam in the mixture will heat by condensation, and therefore the peculiar penetrative quality of steam can be seriously impaired.

Table 1 shows the temperature of various air-steam mixtures at different pressures. It should be studied carefully, because it illustrates the depression of temperature that can occur when air is present in the autoclave. For instance, steam at 15 pounds pressure (as read on the gauge) has a temperature of 250°F if all the air has been removed, but if no air has been removed, the temperature will be only 212°F. This is the temperature of boiling water at sea-level, and is quite unsafe for destruction of spores.

TABLE 1.

AUTOCLAVE TEMPERATURES WITH VARIOUS GAUGE PRESSURES AND DIFFERENT AIR-STEAM MIXTURES.

Guage Pressure –lb./ sq. inch.	Pure Steam– No Air.		⅔ Steam–⅓ Air (20″ Vacuum).		½ Steam–½ Air (15″ Vacuum).		⅓ Steam–⅔ Air (10″ Vacuum).		No Air Discharge.	
	Deg. C.	Deg. F.	Deg. C.	Deg. F.	Deg. C.	Deg. F.	Deg. C.	Deg. F.	Deg. C.	Deg. F
10	115	240	109	228	105	220	100	212	90	193
15	121	250	115	240	112	234	109	228	100	212
20	126	259	121	250	118	245	115	240	109	228
25	130	267	126	259	124	254	121	250	115	240

Removal of air from the autoclave is the most important single duty of the operator. Methods that will effect air removal are detailed on page 22. No person should operate an autoclave who has not a clear understanding of the importance of air removal in attaining an effective sterilizing temperature.

Temperatures higher than 257°F (125°C) are unnecessary and, in addition, they may cause rapid deterioration in certain fabrics. Some organisms are known which will resist these temperatures, but with the exception of *Clostridium botulinum* (sometimes encountered in canned foods) they are non-pathogenic, and are not important in medicine.

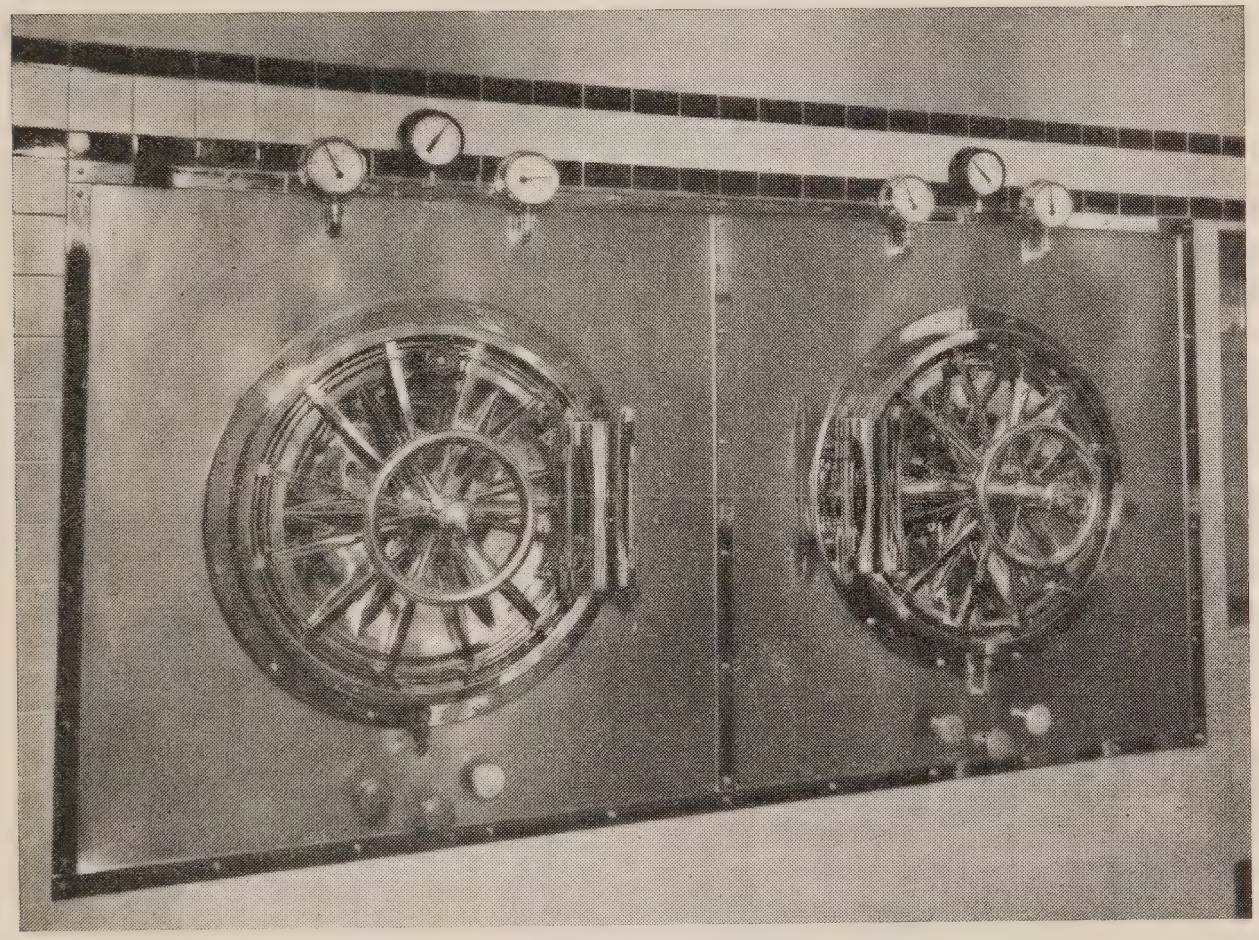

FIGURE 2.

A pair of efficient autoclaves, mounted in a wall. Each autoclave is equipped with a mercury in steel thermometer fitted into the outlet. Thermometer dial is the central dial. The autoclave on the left is operating, and the thermometer registers 250°F. at about 18 pounds of pressure, indicating good air removal.

—*Courtesy Mater Misericordiae Private Hospital, Brisbane.*

Sterilization by Temperature Instead of Pressure.—As stated earlier the sterilizing effect of saturated steam is due to the combination of moisture and temperature. It is not necessary to measure the moisture content of saturated steam because this is constant, but it is absolutely essential to measure the temperature. All autoclaves, therefore, should be fitted with accurate thermometers so placed that they register the temperature of the steam applied to the load at any time during the sterilization process. The thermometer should preferably be placed in the discharge line that drains air and condensate from the chamber (Figure 3). In this position, the thermometer will always register the lowest temperature of the steam in the chamber, and will also respond immediately to any obstruction in the discharge line. Pressure of steam is important to attain effective temperatures—otherwise it is of no significance in the sterilization process. When steam is admitted into the chamber, air is evacuated either automatically or by use of the vacuum. If the autoclave is functioning properly, and air evacuation is good, the thermometer should record 115°C (240°F) within a few minutes after admitting steam to the chamber. Thereafter the temperature should rise steadily, if more slowly, to 120°C (248°F) or even higher. Exposure should be timed to begin when the thermometer registers 120°C. If air evacuation is poor, the thermometer will reach 120°C slowly, if at all, and penetration of steam into the load will be definitely impaired.

Temperature control should therefore replace pressure control.

The selection of a thermometer requires some consideration. Mercury-in-glass thermometers, if calibrated correctly, are extremely accurate and are to be preferred. However, they are apt to break unless protected, and they may be difficult for an inexperienced operator to read unless provided with a magnifying device such as is incorporated in a clinical thermometer. Mercury-in-steel thermometers, which record the temperature on a dial are reasonably satisfactory. (See Figure 2.) Reliable makes are available, but before fitting, each thermometer should be checked for accuracy over the sterilizing range (240°F-260°F). The capillary tube containing mercury should be protected against damage—flattening of the tube at one point will make the thermometer inaccurate. Gas thermometers, which register the temperature on a dial, are less expensive than mercury-in-steel thermometers, but in general are less accurate and even a slight leak may make the instrument ineffective. Devices which record the temperature on a moving dial are not successful unless checked frequently. Indeed, any dial thermometer should be checked periodically against a maximum recording mercury thermometer placed on the bottom of the chamber. Alternatively, a benzoic acid test tube can be used from time to time as a check against the outlet thermometer.

Some confusion has been caused by the term ''thermal death point'' of bacteria. At very high temperatures, bacteria are killed instantly, but at lower temperatures, death depends on the temperature and the time that organisms are exposed to that temperature. For instance, pasteurization of milk can be achieved at a temperature of 162°F for 15 seconds or at a temperature of 145°F for 30 minutes. This kills vegetative organisms but not spores.

As the temperature in an autoclave rises, all organisms of low heat resistance are killed, and by the time the temperature reaches 115°C (240°F) in the dressings, only spore-bearing organisms are alive. A temperature of 115°C (240°F) or, in fact, any temperature between 115°C and 120°C is effective, provided the exposure time is increased. For instance, sterilization which is effective in 10 minutes at 120°C will require at least 30 minutes at 115°C.

Pressure gauges must still be used to regulate the pressure necessary to assure the desired temperature, but it must be remembered that commercial gauges are not highly accurate and that they may become distorted from fatigue after use. Do not trust a pressure gauge if the indicator hand does not return to zero when the autoclave is cold· Such a gauge should receive competent attention or should be replaced.

REQUIREMENTS FOR EFFECTIVE STERILIZATION BY AUTOCLAVE.

Efficient sterilization by autoclave depends on three very important requirements, and these are detailed below:—

(i.) The Autoclave must be efficient.

Steam must be available at sufficient pressure to sterilize all free surfaces of the load within a reasonable period. If two-thirds of the air can be removed from the sterilizing chamber, the maximum temperature reached at 15 pounds pressure will be 115°C (240°F) and at 20 pounds pressure will be 121°C (250°F). Naturally sterilization will occur much quicker at 121°C and in modern autoclaves, the aim should be to reach 120°C (248°F) with 18 to 20 pounds of steam, with an additional pound of steam pressure for every 1,000 feet above sea level.

This pressure should be reached within a reasonable time. With steam laid on, the problem is simple, but where steam is generated by electricity, gas, or other means, pressure may rise very slowly due to three factors:—

(*a*) *Insufficient heat is being applied.*—This is especially true with many electrically heated autoclaves—for instance, an autoclave of 3-5 cubic feet capacity fitted with a 6 K.W. element and a sub-boiler will take at least 45 minutes to raise pressure. Autoclaves of 3-5 cubic feet capacity should have elements capable of developing 9 K.W., autoclaves of 5-7·5 cubic feet capacity should develop 12 K.W., and larger sizes 15 K.W. All electrically-heated autoclaves should have three (3) three-heat control switches to maintain constant pressure of steam as required.

(*b*) *The sub-boiler or its pipes are coated with scale and debris.*—This can occur whenever hard water is used for generating the steam. It is therefore recommended that only soft water (e.g., rain water or chemically softened water) be used in autoclaves, and that if scale is present, expert advice be obtained to remove it. If chemically softened water is to be used, the advice of a qualified engineer should first be sought.

(*c*) *The steam inlet pipes are too small.*—The jacket of the autoclave, if present, must maintain a pressure of rather more than 20 pounds. The steam should be admitted to the sterilizing chamber in such a way (e.g., by baffles) as to give the greatest dispersal and a powerful "swirl" of steam in every direction to facilitate expulsion of the air. The outlet for discharge of steam and condensate should be in the bottom of the chamber, and it would be a distinct advantage if the discharge line were fitted with a thermometer and an efficient thermostatic valve. All dials should be attached to the jacket or chamber by as short a pipe as possible, and all pipes should be of sufficient calibre to allow the dials to show changes of pressure quickly. Pressure gauges should preferably have their own openings into the jacket or sterilizing chamber, independent of all other openings, so as to show the true pressure even when this is changing rapidly, and to obviate inaccurate readings caused by the flowing of steam through pipes to which the gauges may be attached.

If a thermometer is not fitted to the outlet, a thermometer or other accurate temperature recording instrument should be fitted into the chamber, because some form of temperature control is essential.

Finally, an autoclave should have some device whereby at least two-thirds of the air can be removed from the chamber. If a vacuum apparatus is fitted it should be capable of rapidly attaining a vacuum of at least 10 inches of mercury without causing undue fluctuation in steam pressure. Adequate air removal is discussed in the next section.

(ii.) The autoclave must be intelligently operated.

The degree of safety attained with almost any autoclave depends largely on the skill and vigilance of the operator; especially in those types where air discharge is not automatic and where manipulation of valves is necessary for air evacuation.

Failure of the thermometer to indicate an effective sterilizing temperature may have the following causes:—

(*a*) *The pressure of steam is inadequate.*—There may be some interference with the supply of steam—faulty elements, coated boiler, faulty reducing valve, &c.; or, secondly, the gauge may be inaccurate; or thirdly, steam may be leaking from some part of the sterilizer. The fault must be rectified.

(*b*) *Air discharge is unsatisfactory.*—This may be due to a faulty thermostatic valve or steam trap, or else shreds of cotton, grease, and other debris may be blocking the discharge line. Blocking of the discharge line will rarely occur if a gauze filter is fitted over or into the outlet in the chamber. A blocked or impeded discharge line may be cleared by pouring in hot caustic soda solution, hot tri-sodium phosphate solution, or an organic detergent solution, assisted where necessary by mechanical removal. In autoclaves not fitted with automatic air discharge, the vacuum apparatus, or the technique of using it, may be faulty.

(*c*) *The thermometer is inaccurate.*—This will happen very rarely with mercury thermometers, but dial thermometers and automatic temperature recorders are liable to the same error as pressure gauges.

Removal of Air from the Chamber.

Where air discharge is not automatic, this is the most important duty of the autoclave operator. Air can be removed from the chamber in three ways—by vacuum attachment, by manual manipulation of the discharge line, and automatically by an efficient thermostatic valve, or by a combination of these methods.

Meaning and Use of Vacuum.—A great deal of misunderstanding has arisen on the vacuum. By itself it plays no part in sterilizing; removal of air only enables a higher temperature to be reached by the steam. A perfect vacuum contains no air, and will sustain a column of mercury 30 in. high. The combination vacuum-pressure gauges in use are graduated for determining the degree of vacuum in inches of mercury. A 10-in. vacuum means that one-third of the air ($\frac{10}{30}$) has been removed—a 15-in. vacuum indicates removal of half of the air.

The usual vacuum type autoclave is equipped with an ejector valve which will produce a 10-in. vacuum when the instrument is new, but which may not attain this figure as the autoclave ages. In an autoclave working properly at 15 pounds of steam, evacuation of one-third of the air will give a maximum chamber temperature of 228°F (109°C) which must be considered inadequate. If the autoclave works at 20 pounds, a single evacuation of air will give a chamber temperature of 240°F (115°C), which is at the lower end of the sterilizing range (see Table 1).

It is quite apparent, therefore, that too much reliance should not be placed on the vacuum system of removing air unless the thermometer indicates that an effective sterilizing temperature has been reached. The more air is removed the better will steam penetrate into packages. As air is exhausted from the chamber, creating reduced atmospheric pressure, air inside and around bundles will escape into the chamber, enabling steam to enter and thereby raising the internal temperature of packages. If no air has been removed, not only will the air absorb much of the heat from the steam, but air pockets in and around bundles of dressings will tend to remain, and will greatly retard the entrance of steam.

In vacuum type autoclaves not fitted with a thermostatic valve, not more than one-third of the air can be removed by the usual single application of vacuum, and the occasional opening of the chamber drain valve to discharge condensate will get rid of a little more. Unless a thermometer is fitted, the performance of such a machine is always a matter of guess work, though in skilled hands results may be satisfactory. These autoclaves, if otherwise in good order, can be made more efficient by installing a thermometer and a good thermostatic valve on the discharge line. Air evacuation should be maintained until the vacuum has reached its maximum, and should then be turned off. From this point on, if the machine has no thermometer and no thermostatic valve, there are three procedures that will remove more air, though they add time to the autoclaving:—

(*a*) *By using the vacuum more than once.*—Two techniques are available, of which the first is the more satisfactory. In this method, when the jacket gauge registers 20 pounds pressure, steam is admitted to the chamber until the compound gauge registers 18-20 pounds pressure. The mixture of air and steam is then evacuated through the outlet and a vacuum applied until the compound gauge registers approximately 10 inches of vacuum. The vacuum is turned off and steam is again admitted to the chamber. This time the temperature should rise higher and should reach the maximum more quickly, because one-third of the air has been removed. If the thermometer fails to reach 120°C (248°F) the process is repeated until this temperature is attained. By repeated use of the vacuum, an autoclave operating at 15 pounds pressure can be rendered efficient, but the process is time consuming and some goods (e.g. rubber) do not withstand many such treatments.

The second method is to turn on a vacuum when the jacket gauge records 20 pounds pressure. Steam is not admitted to the chamber. When a vacuum of 10 inches is reached, steam is admitted to the chamber. If the thermometer does not now record 120°C (248°F), the mixture of steam and air in the chamber is again evacuated as in the first method, and if necessary, the process is repeated until the thermometer records 120°C (248°F).

Once the procedure is determined for a particular autoclave, it should become standard practice.

(*b*) *By blowing steam through the chamber.*—When working pressure is reached in the jacket, steam is admitted to the loaded sterilizing chamber. It usually creates a powerful swirl, mixing the air with steam, and forces air and steam through a discharge line, at the bottom of the chamber, which by-passes the thermostatic valve or steam trap. Steam is blown through the chamber for a variable time (10 to 15 minutes). The exact time may be determined by experience (i.e., noting the maximum temperatures attained after steam has blown through for different times), or by the following simple method: When steam has been blowing for several minutes, the process is stopped, and a rubber tube is attached to the discharge line. The other end of the tube dips beneath water in a bucket. Steam is again admitted to the chamber, the discharge valve opened, and a mixture of air and steam passes into the water. The steam condenses at once, but the air rises as bubbles. The water in the bucket will be found to become quite hot, and in fact, may even start to boil after a time. Therefore, the hot water should be replaced by fresh cold water. When bubbling has almost ceased, most of the air will have been removed. The discharge valve is closed, the tube is withdrawn and sterilization may be timed to commence as soon as the thermometer records 248°F. This method of air elimination has been found by test to be very effective.

(*c*) *By manipulation of discharge line valve.*—This can be done only by expert operators who understand the mechanism involved and the results to be achieved, and is not recommended for routine use in hospitals.

Evacuation by Thermostatic Valve.—The aim of manufacturers in recent years has been to evolve some system which will automatically remove air and condensate from the sterilizing chamber without reliance on any mechanism other than perhaps an initial application of the vacuum apparatus (Figure 3). Specially designed and adjusted thermostatic valves have been developed to meet this problem. The valve contains an expansion element filled with volatile liquid, which contracts when cool,

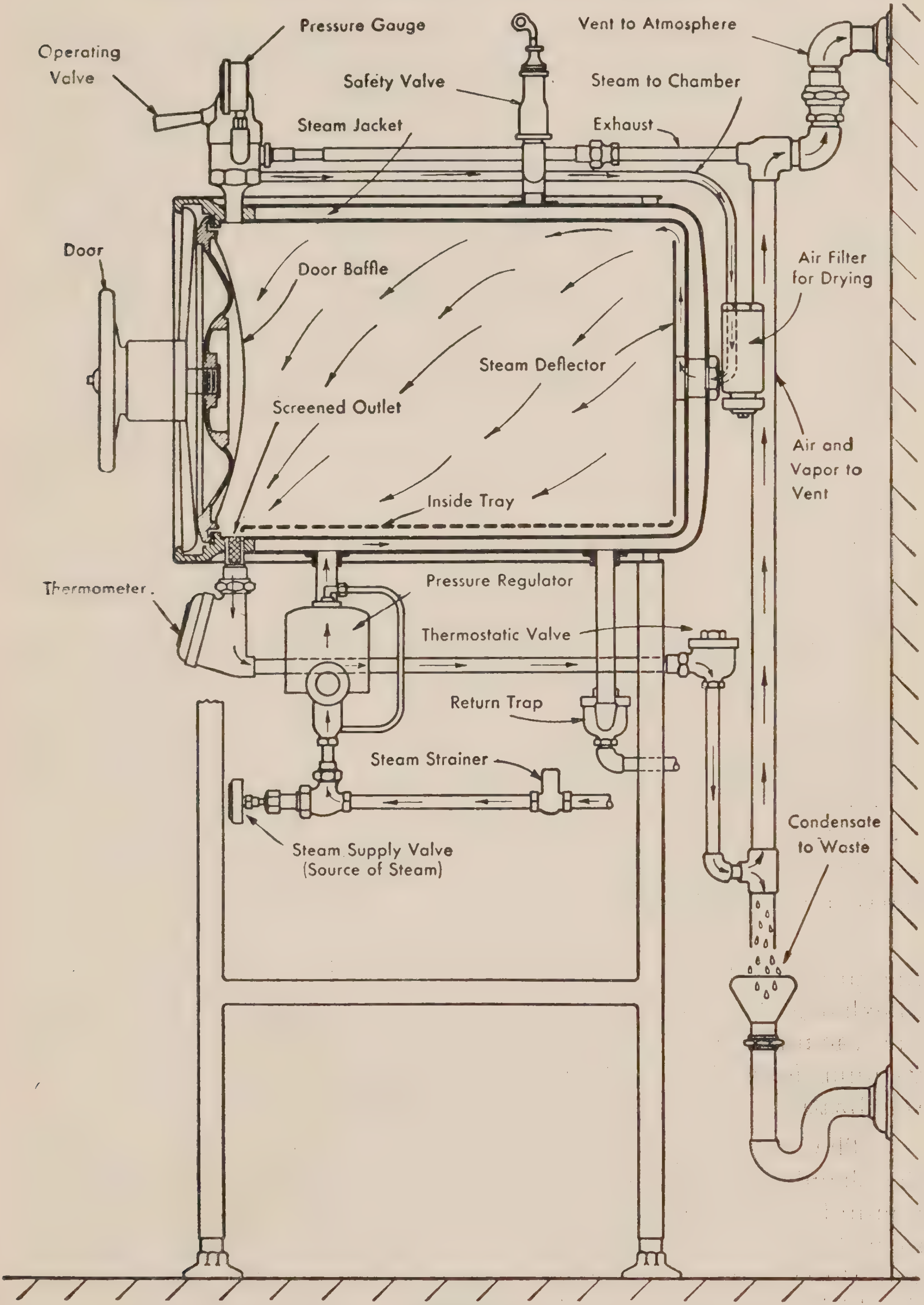

FIGURE 3.

Longitudinal section of modern pressure steam sterilizer. Steam is delivered from the source to the steam jacket through a pressure regulator which automatically maintains the desired range. The same principle applies for steam heat (as indicated) or for gas or electrically heated sterilizers. Note position of thermometer.

—*Courtesy American Sterilizer Company.*

opening the discharge line, in much the same way as the hand operated valve. When the expansion element is heated, it expands and partly or completely closes the discharge line. It can be set to close at any desired temperature. Sensitive thermostatic valves will permit rapid and almost complete evacuation of air and condensate from the chamber, without using the vacuum attachment. If such a valve is fitted to a vacuum-type autoclave, with adequate steam supply, performance will be greatly improved, but it must be situated about three feet along the discharge pipe or it may shut off too quickly, leaving some air still in the chamber. Some thermostatic valves are unsatisfactory and all are liable to get out of order or become fatigued after long use. In addition, valves may become clogged with threads or with organic matter. Every valve should be checked periodically, and it is wise to stock a spare valve to replace a valve returned to the maker for adjustment.

If the thermostatic valve is in good order, air evacuation will be satisfactory, and a temperature exceeding 120°C (248°F) should quickly be reached in the discharge line at 20 pounds of steam pressure. As the valve ages, however, its performance might become unreliable, and the operator therefore should watch the thermometer closely to note the maximum temperature attained in the steam outlet. Unless a temperature exceeding 120°C (248°F) is reached within five minutes after turning steam into the chamber, it is recommended that an initial vacuum be applied. There are two methods of doing this, and the operator should use whichever method is found satisfactory for the particular autoclave.

The first method is to run steam into the chamber. When the pressure has reached its maximum, the vacuum is applied to exhaust the mixture of air and steam from the chamber. When the vacuum has reached its maximum (usually 10 inches), the vacuum is broken and steam is admitted to the chamber for sterilization.

The second method is to apply the vacuum once or twice to the chamber containing air but no steam. Vacuum is applied for a minute or two after it attains its maximum reading, and is then turned off. Two vacuums can be applied in about six minutes, and three vacuums in about eleven minutes (three applications should be adequate to reach an effective temperature).

When preliminary vacuums have been applied to the loaded autoclave it has been observed that the maximum temperature in the chamber is often reached more quickly than when the thermostatic valve alone is used.

The discharge outlet should be watched when steam is turned into the chamber. If no vapour at all escapes, or if vapour escape is feeble, or if it escapes profusely for a minute or two only, the valve is probably faulty. This can be checked with a thermometer—it will fail to reach the sterilizing range of temperature, even though the pressure gauge may be reading 20 pounds. If the thermostatic valve is not faulty, the discharge line is probably clogged and should be cleared. The trouble, whatever its cause, should be corrected before the autoclave is used.

NOTE: It is necessary to have a break in the discharge line which can easily be inspected. This protects against the possibility of suction from a drain.

(iii.) The Autoclave must be properly loaded.

In loading an autoclave, attention must be paid to two basic requirements:—

(*a*) There should be room in the chamber for the free interchange of steam with air.

(*b*) The bundles or packages should be of such a size and density and so arranged in the chamber that steam will penetrate every free surface with a minimum of delay.

A sterilizer whose chamber is tightly packed with bundles will be inefficient, because there is too little room for the exchange of steam and air, and steam penetration into the bundles will be

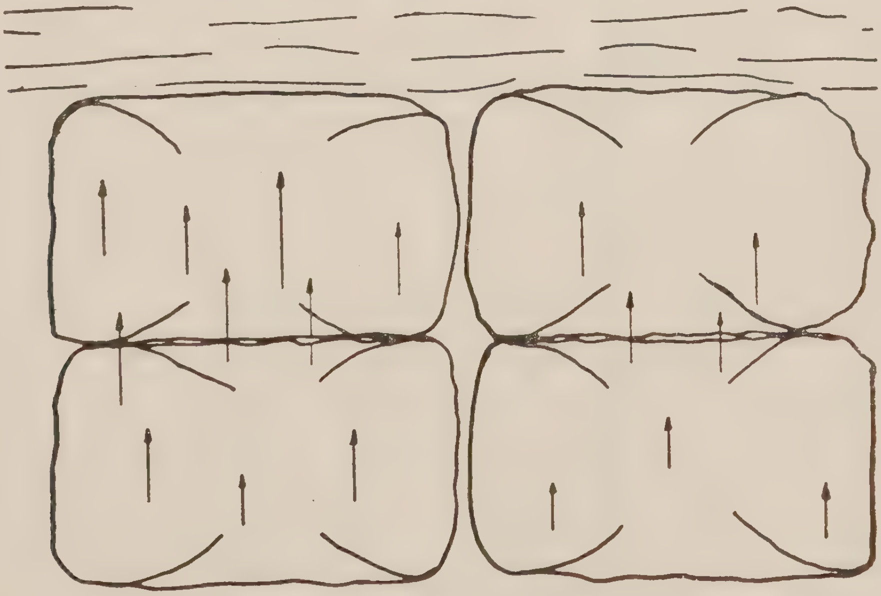

FIGURE 4.

Large packs placed in the sterilizer as shown here are difficult to sterilize, the effect being to double the thickness of each pack. Packs such as these must be separated by a porous shelf to enable steam to enter from all sides.

—*Courtesy American Sterilizer Company.*

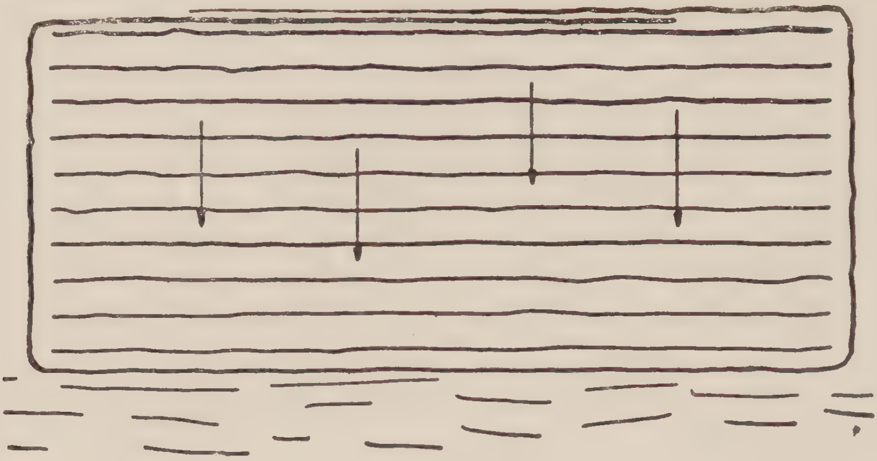

FIGURE 5.

This pack is laid with the folding horizontal. Steam descends vertically and will have to penetrate all layers in the pack. Steam penetration will be slow if the pack is large.

—Courtesy American Sterilizer Company.

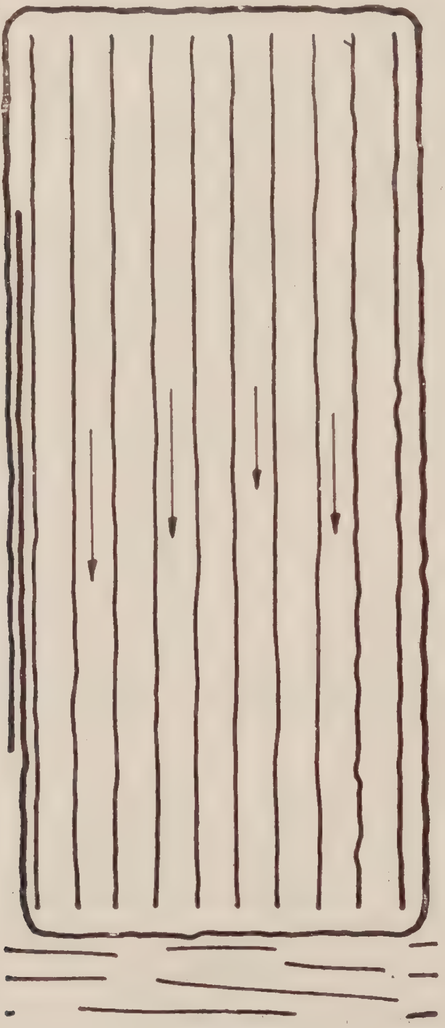

FIGURE 6.

If the pack shown in Figure 5 is placed on edge with the folds of fabric lying vertically steam penetration will be more rapid.

—Courtesy American Sterilizer Company.

impaired. There should be no other packs in contact with heavy packs, and in all cases there should be some space left between the packs to allow free penetration of steam. Keep some open space above the bundles for the exchange of steam. If packs have to be arranged in layers, see that the layers are separated by at least half an inch of space. This can be done by using wire shelves or using wooden or metal slats. If steam has access to every surface of every pack it does not matter how many packages are placed in the sterilizer, but heavier packs should be placed at the bottom of the chamber. No load should exceed two-thirds of the capacity of the chamber.

The perforated metal tray at the bottom of the sterilizer permits the release of air pockets from the load to the level of the outlet, and also prevents the packages from becoming saturated with condensate. It should, therefore, always lift the load clear of the bottom of the chamber.

The size and method of arranging packages will be dealt with under the various headings, e.g., linen, instruments, &c.

STERILIZATION OF LINEN AND DRESSINGS.

Once air has been withdrawn from the chamber and steam turned on, the chamber should show a rapid increase in pressure and in temperature. The thermometer will advance rapidly to 230°-240°F, and thereafter the rise will be less rapid. When the free air around the load has been driven out, there will only be slow mixing of gases due to the release of air from the load itself. A good thermostatic valve will evacuate this air, and the temperature in the load should approximate that of the chamber after a time lag of from five minutes to forty-five minutes, depending on the size and density of the packages.

A pack six inches thick will take twice as long for adequate steam penetration as a similar pack which is three inches thick. If two packs each six inches thick are placed together in close contact, the effect will be the same as if both were wrapped in one pack twelve inches thick (Figure 4).

As steam penetrates from above downward, it is important to remember that all packs should be prepared and arranged in such a manner in the chamber that steam will have least resistance. Assume that six towels are folded and wrapped into a pack. If the pack is placed so that the air and steam will have to penetrate all thicknesses of folding, the exchange of steam and air will be hindered, as can be seen in Figure 5.

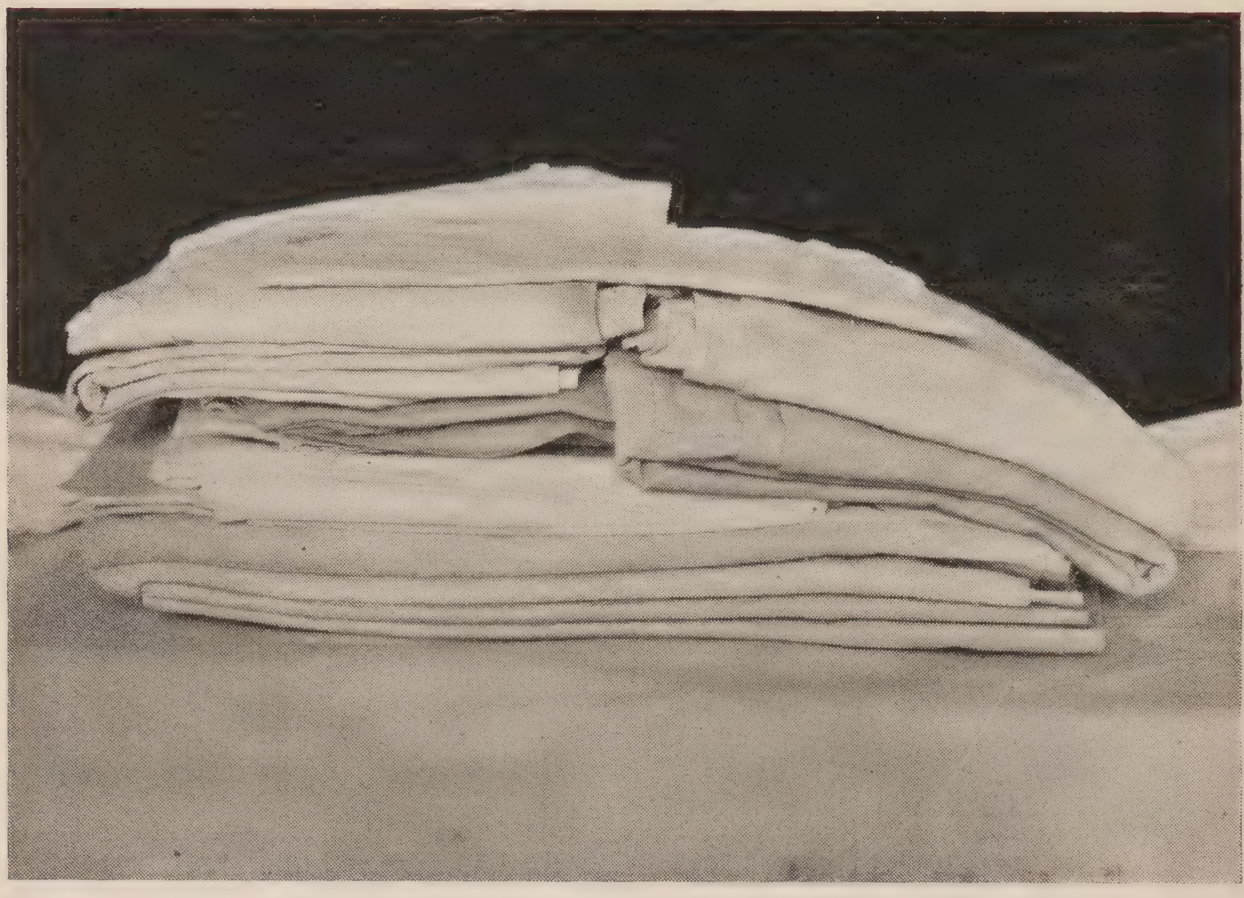

FIGURE 7.

Surgical pack. This pack is the maximum size advocated. It contains 3 body sheets, 3 small sheets, 2 small abdominal sheets, 2 gynaecological sheets, and 4 dressing towels. It weighs 8¾ pounds.

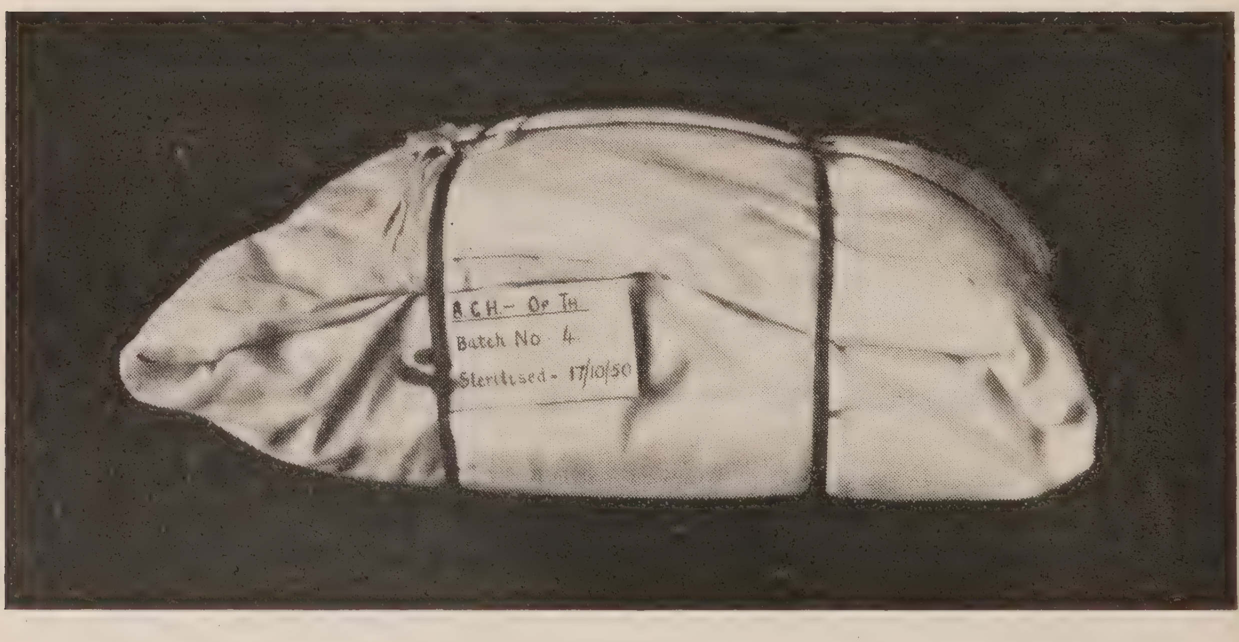

FIGURE 8.

Surgical pack. The pack illustrated in Figure 7 has been wrapped in a double thickness of sheeting. It is then pinned or tied with tapes before being labelled, as shown. If fastened with safety pins, these shoud not penetrate the inside layer of sheeting.

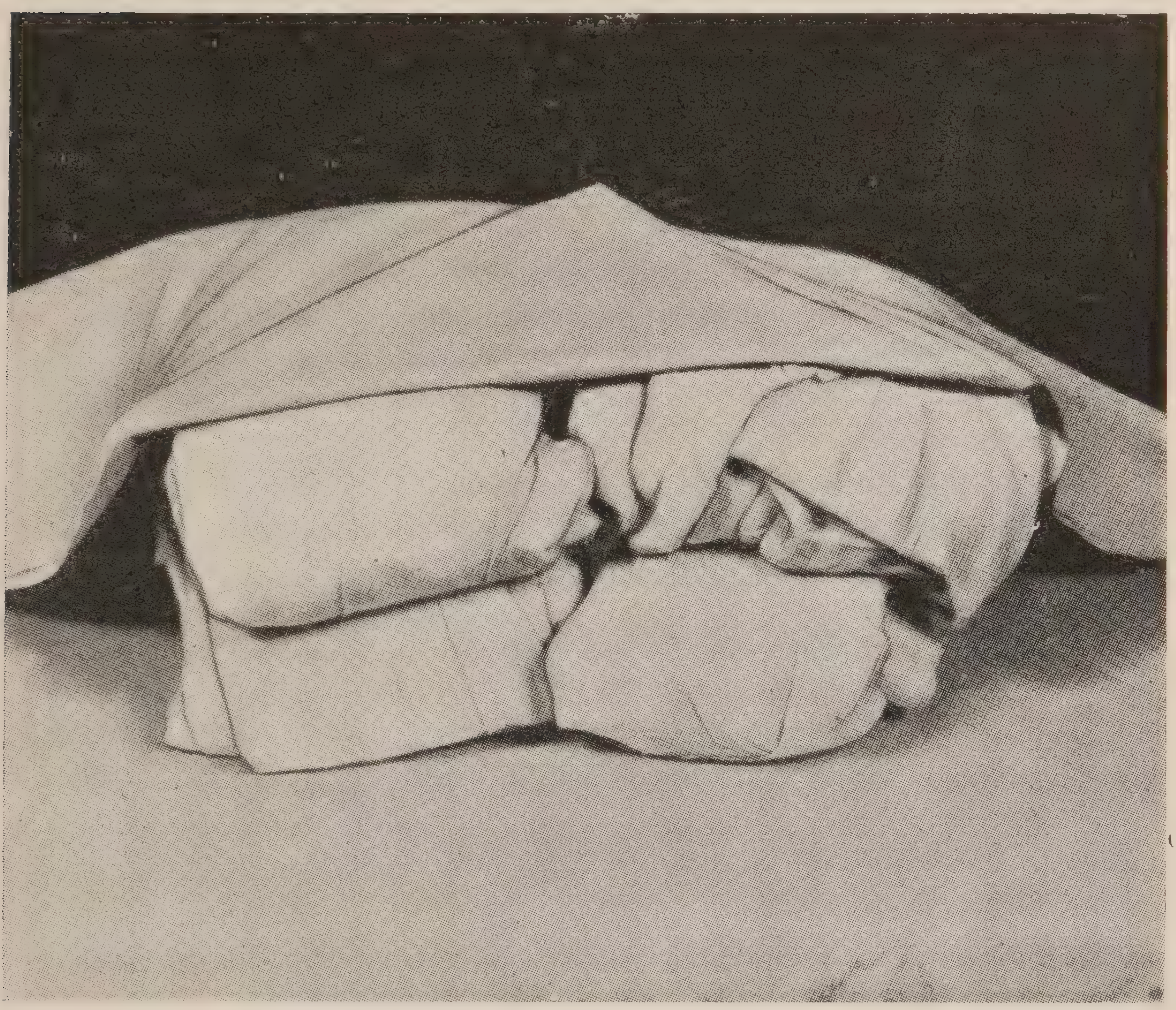

FIGURE 9.
Four surgeon's gowns can readily be sterilized in one bundle. They are wrapped in a double thickness of good-quality sheeting.

On the other hand, if the bundle is placed so that the space between the layers is vertical instead of horizontal, steam penetration is more rapid and certain, and air can escape more easily. (Figure 6.) The more layers there are from top to bottom, and the tighter the weave of the fabric, the more difficult will be the penetration. This rule should guide the operator in preparing every pack. Wherever possible, linen in a pack should be folded the same way and items should not be arranged criss-cross.

The packs should never be too large—the old days when every item of linen for a major operation was sterilized in one parcel are over. Large bundles are definitely hazardous. In an efficient autoclave, no package should exceed 10 inches by 5 inches by 15 inches, or about 10 pounds by weight and the majority should be much smaller (Figures 7, 8 and 9). Big packages require such prolonged time for safe sterilization that some deterioration in the fabric is almost inevitable (Figure 10). Properly packed bundles should be sterilized at 120°C (248°F) for 30 minutes. Small bundles (less than 4 pounds by weight) can be sterilized in 20 minutes, but it is a good general rule that dressings of all kinds should be sterilized for the full half hour.

Packs should preferably be wrapped in a double layer of light porous cotton material (Figure 8), and each package should bear the date of sterilization. This marking can be done with a pencil on the cover, but a paper or cardboard tag attached to the edge of the outer cover by a safety pin or by tape is preferred. The label should state the batch number and the date. For instance, if a certain package was in the third load sterilized on a particular day the label would state Batch No. 3, followed by the date. The operator or person in charge of the sterilization should keep a book in which the following particulars are entered:—

(i.) Date.

(ii.) Batch number.

(iii.) Number of items in load.

(iv.) Time of commencing sterilization. Temperature. Pressure.

(v.) Time of completing sterilization. Temperature. Pressure.

(vi.) Time of applying final vacuum from the instant when 10 inches of vacuum is reached.

If properly wrapped packages of linen are placed in a dust proof cupboard after sterilization they will remain sterile for at least a week.

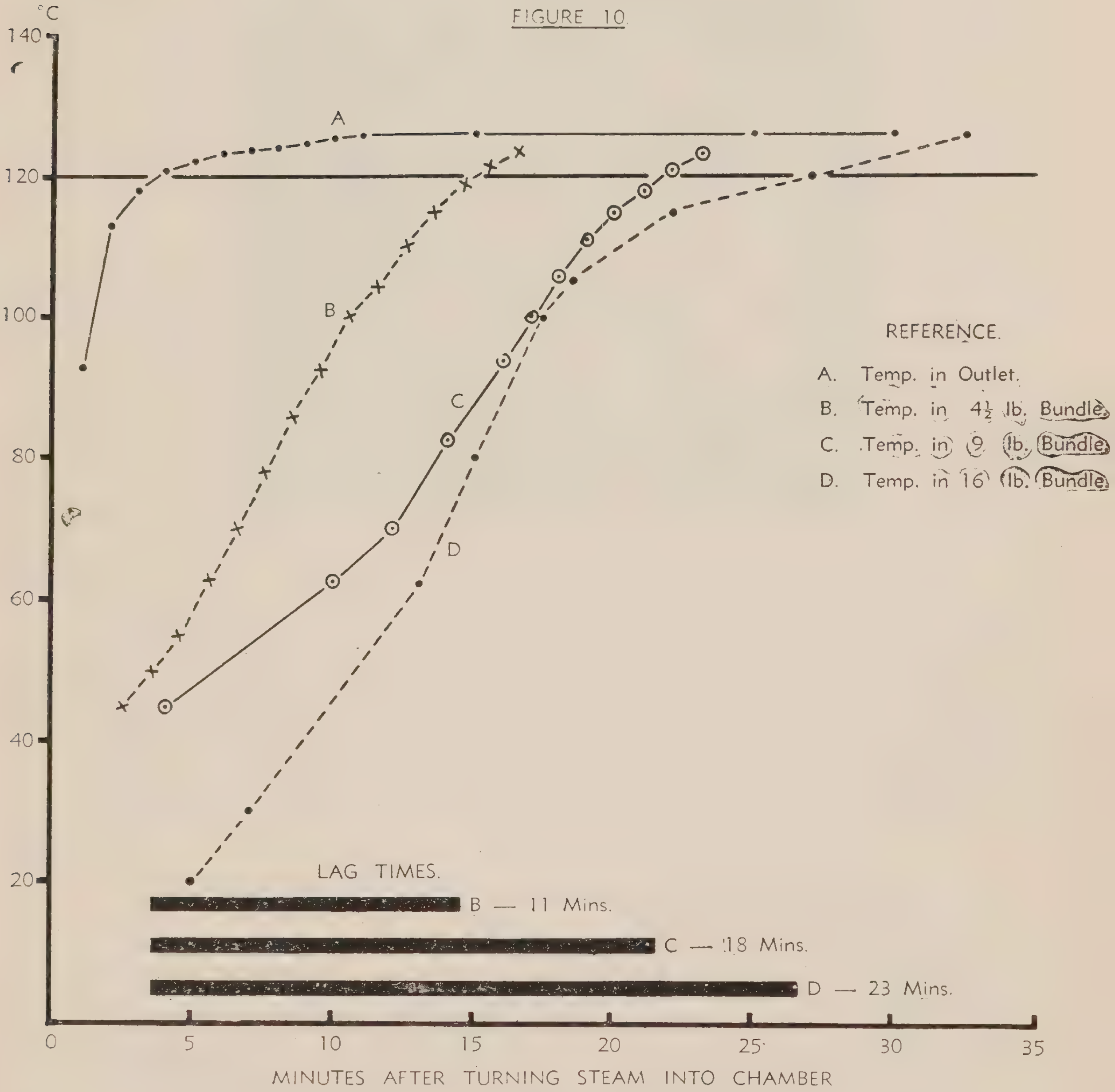

FIGURE 10.

Showing lag times with surgical packs of various weights. Note that the heavier the pack the longer the temperature in the centre of the bundle takes to reach 120°C.

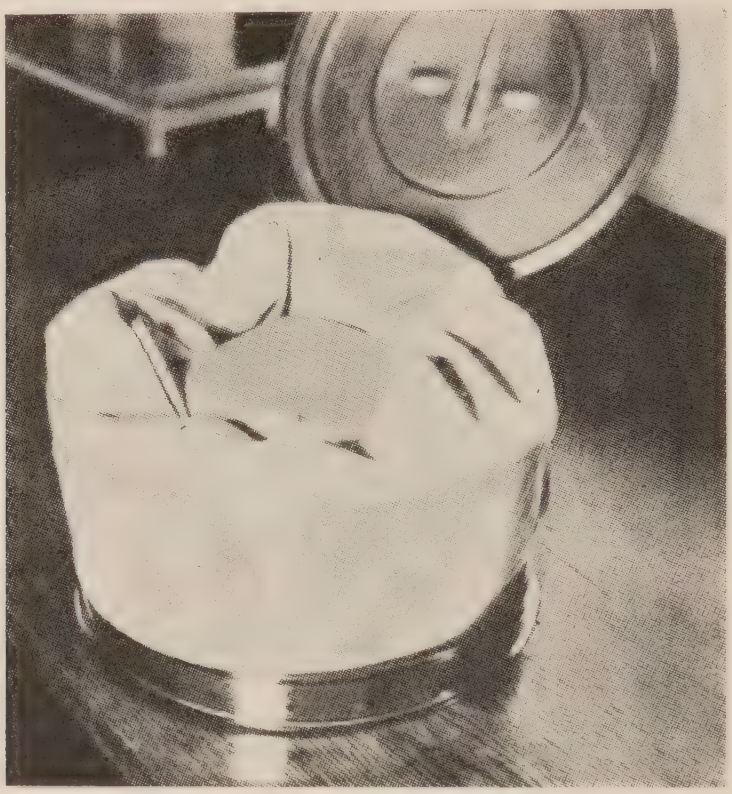

FIGURE 11.

Showing one method of packing a drum. A double thickness of sheeting is placed inside the drum as a lining and is sufficiently large to act as a drape over the edges when the drum is opened. All articles in the drum are folded flat, and some space is left at the top for the interchange of air and steam. Drums, if used at all, should never be packed tightly; they should be placed on their sides in the sterilizer. Canvas covers are not porous and should not be used.

—Courtesy American Sterilizer Company.

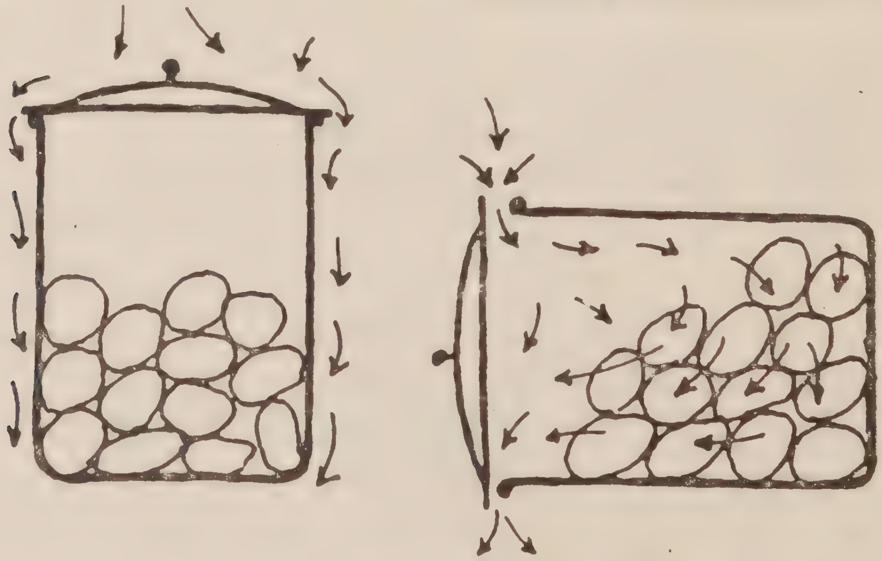

FIGURE 12.

Sterilization of small dressings or pledgets in container. With the lid on and the container vertical, there can be little penetration of steam. The container should be laid on its side with the lid ajar. Containers like this should never be more than half full.

—Courtesy American Sterilizer Company.

STERILIZATION IN DRUMS.

Material in a drum can never be exposed to steam as easily as if wrapped in a double thickness of light cotton cloth, and consequently sterilization is more hazardous. Furthermore, a common tendency is to overload the drum, so that the material is compressed and no free air space exists. When the drum is being packed, material should be laid flat so that when the drum is placed on edge in the sterilizer the load will be vertical. A space should always be left at the top of the drum (Figure 11).

The usual drum with port-holes and sliding bands should not be used. Sometimes drums will be placed accidentally in the sterilizer with the portholes closed, and in these cimcumstances it is almost impossible to achieve sterilization. It is better to remove sliding bands, where present, and to make additional portholes in the drum. The sliding band was introduced to make the drum dust-proof but is unreliable for this purpose. A double layer of muslin, either inside or outside the drum, is a more effective filter, and packs or drums so wrapped remain sterile for at least a week.

Drums should not be wrapped in canvas covers which, being tightly woven, will interfere seriously with steam penetration. On the other hand, light material such as muslin or old sheeting should not be used if it is thin or has holes in it.

It is recommended that sterilization in drums be abandoned. If drums are used they should be sterilized when empty and used only for the storage of previously sterilized wrapped packages. If sterilizing dressings in drums, sterilize at 120°C (248°F) for 45 minutes.

STERILIZATION IN METAL CANS.

Bundles of small dressings or cotton wool pledgets are frequently sterilized in metal or enamelware containers. This method is open to objection, as there are no vents for escape of air or entry of steam, and the only entry is through the open end. Containers such as this must be very loosely packed, covered with a double thickness of muslin, and sterilized lying on the side with the lid removed. It is a good rule to remember that the air in an empty container is like water, and every container should be so placed in the sterilizer that, if it contained water, the water would flow out. This generally means laying the vessel or container on its side, and applies to jugs, test tubes, flasks, bowls, drums, &c. (Figure 12). Sterilize for 30 minutes at 120°C (248°F).

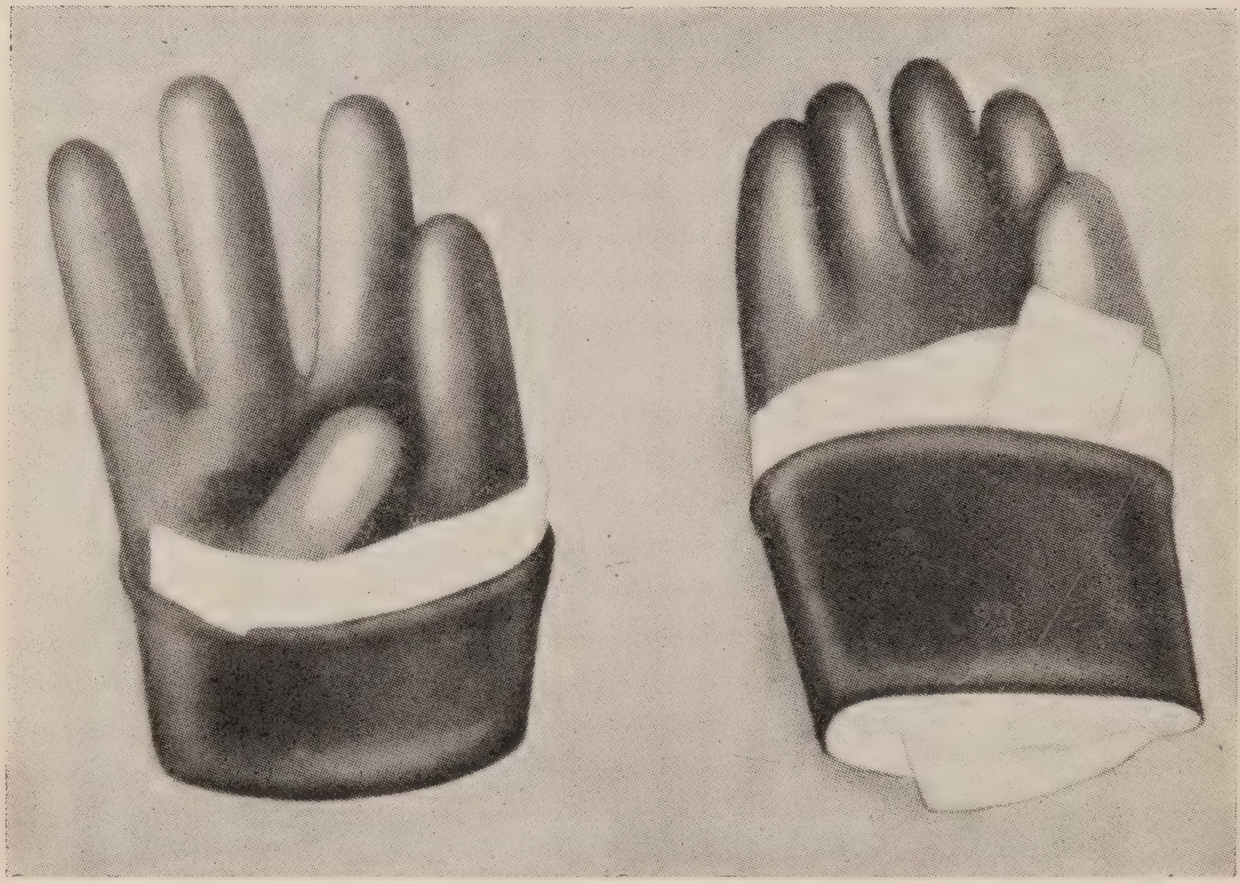

FIGURE 13.

When preparing gloves for sterilization, the wrist should be folded down over a layer of gauze or muslin. To assist in keeping the fingers open, it is advisable to place inside the palm of the glove a pad of gauze or a large powder puff. This will enable steam to contact the interior surfaces.

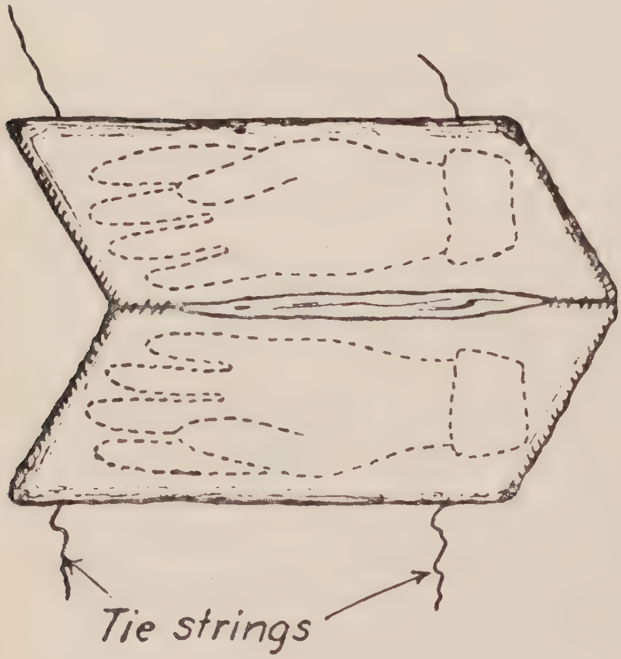

FIGURE 14.

This is a satisfactory envelope for gloves. It is made of a double thickness of gauze, and is shaped like a bill-fold, with one pocket on each side for a glove. The pocket should be 11½ inches long and 5 inches wide. The glove, with the cuff folded down, and a piece of gauze inside the palm, should be placed inside the pocket, so that it is at least 1 inch from the open end of the pocket. A gauze collar inside the folded part of the cuff prevents contact of the rubber surfaces. The envelope is fastened with tie strings.

—*Courtesy American Sterilizer Company.*

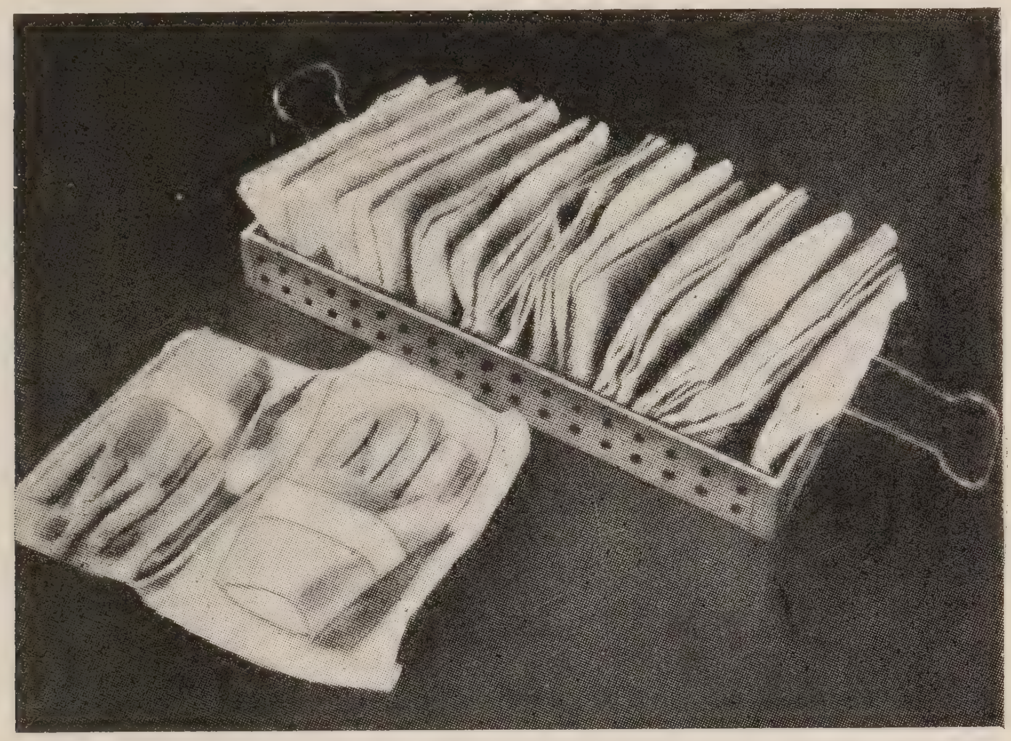

FIGURE 15.

Showing gloves in envelopes loosely stacked in a porous tray before being placed in the autoclave. The gloves have gauze placed inside the turned-down cuff and have a gauze pad inside the palm to enable steam to enter the fingers. Gloves and tubing should be sterilized separately from other material, as they require less prolonged exposure.

—*Courtesy American Sterilizer Company.*

DRYING OF DRESSINGS.

It is important that dressings should be dry when removed from the autoclave, otherwise troublesome mould growth may occur.

The usual method of drying the load after sterilization is to turn off steam from the chamber and apply a vacuum. If a 10-inch vacuum can be reached, the gauge should read 10 inches within five minutes of applying the vacuum. Once the maximum reading has been attained, keep the vacuum applied for a period of ten minutes; after closing the vacuum, partly open the door of the autoclave, allow surplus steam to escape, and preferably allow the dressings to remain in the chamber for fifteen minutes whilst steam is still circulating in the jacket. The radiant heat from the walls of the chamber will aid drying.

If the vacuum will not reach 10 inches of mercury, the check valve on the discharge line should be inspected for clogging. If the check valve is in order, a more efficient ejector should be fitted, because a low vacuum will definitely retard drying.

When dressings are placed in the chamber prior to sterilization, care should be taken to see that no package is in contact with the bottom or with the door, otherwise it may become saturated with condensate. If dressings from one end of the autoclave are wet, it may be found that the autoclave is not level. This should be corrected.

A more elaborate method of drying, consisting of circulation of filtered air through the autoclave while holding a vacuum, is not generally available in Australia.

STERILIZATION OF RUBBER GLOVES.

Rubber gloves deteriorate rapidly if the temperature is too high or if the exposure period is too prolonged. The object should be to sterilize them in 15 minutes at a temperature of approximately 248°F (120°C), and it is a distinct advantage if the autoclave reaches this temperature quickly.

Gloves should be packed in such a way that steam can have access to all surfaces. Steam cannot enter if the fingers of the glove are collapsed or kinked.

The gloves should be carefully washed and dried to remove all traces of foreign material and should then be matched in pairs. The cuff of the glove is turned back over a thin pad of gauze, and a thicker pad of gauze or a small powder puff is inserted into the palm of the glove to keep the fingers reasonably open (Figure 13). Each pair of gloves is then placed in a gauze envelope, made like a bill-fold, in such a way that the surfaces of one glove are not in contact with the other glove. The envelope should measure approximately 11½ inches long by 5 inches wide (Figure 14). Envelopes containing gloves are then placed upright in a perforated tray, very loosely packed, so that no pressure is applied which might force any two surfaces of the glove (e.g., the fingers) in contact with each other (Figure 15).

Gloves and rubber tubing should always be sterilized separately from other material. This avoids overcrowding and ensures that exposure is not too prolonged.

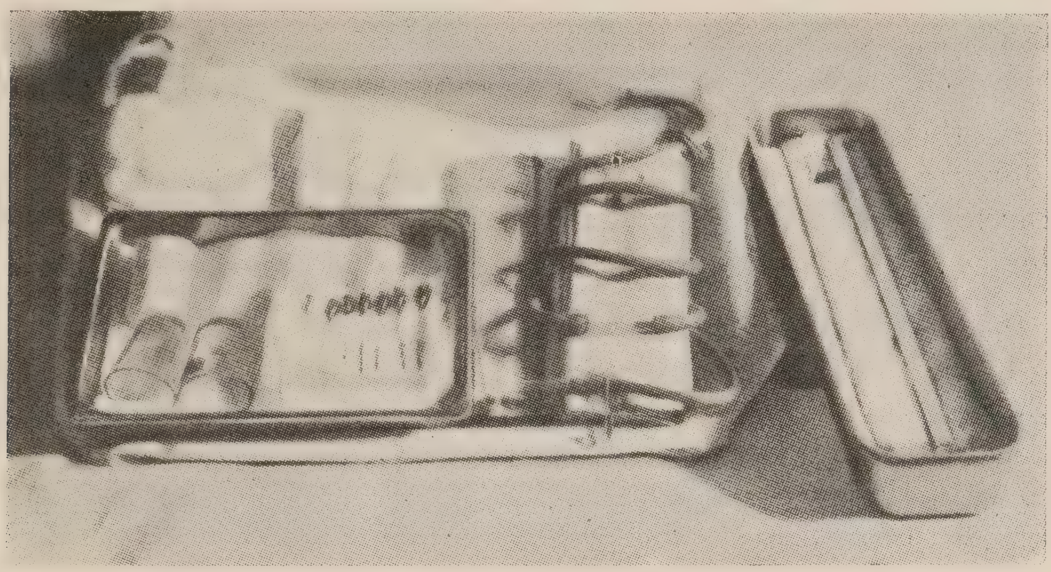

FIGURE 16.

It is difficult for steam to penetrate into rubber tubing. An infusion set such as this has air in the glass cylinder and in the tubing. To induce displacement of the air by steam, the tubing is folded loosely around two towels, and the tray is sterilized in a tilted position (as close to vertical as possible). Similarly, the tray containing the manometer on the right is placed vertically in the autoclave before being sterilized.

—Courtesy American Sterilizer Company.

STERILIZATION OF RUBBER TUBING FOR INTRAVENOUS THERAPY.

For heat sterilization it is necessary to procure rubber tubing of the highest quality. Even then some brands will be found to deteriorate quickly.

Preparation of new rubber tubing.—New tubing is first cut to the required lengths, rolled on a hard surface with the hand to loosen any adhering powder, and then boiled for fifteen minutes in a 5% solution of sodium bicarbonate. Tap water, from a jet, is then run through for a few minutes, followed by three rinsings with freshly-distilled water (not more than six (6) preferably not more than three (3) hours old).

Preparation of used tubing.—Dirty tubing is flushed on the jet and rinsed with three (3) changes of freshly distilled water.

For sterilization, the tubing is carefully and loosely spiralled round a muslin covered cylinder (a jug or a bundle of hand towels) in such a way that it is not restricted and steam and air can flow freely from the top to the bottom (Figure 16). Tubing should then be sterilized with the cylinder *upright* at 120°C (248°F) for 15 minutes, as for gloves.

STERILIZATION OF RUBBER DRAPES, TABLE COVERS AND APRONS.

As these articles are impervious to steam, they are difficult to sterilize. Steam, therefore, must have equal access to both surfaces, and this is a real problem when the articles have to be folded to fit in the sterilizer, thereby creating pockets of air.

Perhaps the most practical way is to clean the article thoroughly with soap and water, fold once, place inside the fold a layer of gauze ($\frac{1}{2}$ inch in thickness), roll very loosely, place in a muslin bag, and sterilize (upright if possible) at 120°C (248°F) for 20 minutes. The outer surface should be the only surface to be regarded as sterile.

STERILIZATION OF GLASSWARE AND SOLUTIONS FOR USE WITH INTRAVENOUS APPARATUS.

Preparation of Glassware.—The glassware is washed thoroughly in soap and water, then rinsed twice in very hot water (preferably soft water). It is then soaked for several hours in the cleaning fluid, rinsed six times in hot water, and finally rinsed twice in freshly-distilled water. Do not dry with a cloth.

Formula for cleaning fluid.

Dichromate of Potash	1 part
Sulphuric Acid	1 part
Distilled Water	10 parts

Dissolve the potassium dichromate in the water with heat, in a flask, then cool. Add the sulphuric acid very slowly to the solution. Never pour the solution into the acid, as they may boil and cause splashing. This solution can be used repeatedly until it becomes green, when it should be discarded.

NOTE: This solution may corrode the skin.

Preparation of Solutions.—Emphasis is rightly placed upon the freshness of the distilled water. There are many organisms present in the atmosphere and in tap water, which are capable of sufficient development in distilled water within a space of three to six hours to cause pyrogenic reaction if this water is used for intravenous injection. Distilled water should be kept in glass containers, thrice rinsed with fresh distilled water before being used for collection. Pyrex glass is not affected by distilled water. The containers should be kept corked, and preferably should have a linen dust-proof cover over the cork. All solutions should be prepared in a room that is free from air currents and dust.

It is of prime importance that whenever distilled water is to be stored, it be sterilised within three hours of preparation.

Sterilization of Solutions in Flasks and Bottles.

While the solution is being heated in the sterilizer, it will not boil, because the pressure of steam in the chamber is greater than the pressure in the fluid, but boiling does occur during the process of cooling, especially if the pressure is reduced rapidly, when corks are liable to be blown out and solution may be lost. Therefore, the pressure should be reduced gradually over a period of 7-10 minutes. Even when cooling is gradual, loss from evaporation may be as high as 3-5%, so it is wise to add about 5% more water to the flask prior to sterilization to allow for this. Too prolonged cooling, on the other hand, may cause slight caramelization in glucose solutions and may cause deterioration in others.

TABLE 2.

RECOMMENDED EXPOSURE TIMES FOR AUTOCLAVING.

Item.	Exposure at 120°C (248°F).
Instruments in trays (cotton covers)	15 minutes
Utensils in muslin covers	15 minutes
Rubber gloves in cotton bill-fold covers	15 minutes
Theatre packs (double cotton cover, maximum weight 8–9 lbs.)	30 minutes
Theatre packs in drums with cotton liner	45–60 minutes
Most solutions (depending on volume)	20–30 minutes

Exposure timed from when thermometer reaches 120° C.

When removed from the sterilizer, the temperature of fluids will still be high, and, as they cool, there is a definite intake of air, known as "breathing." Unless this air can be filtered, contamination may result. Fluted paper, tied with tapes around the neck of the flask, is satisfactory. Less satisfactory is a light cotton wool plug with an outer layer of gauze, which filters the air, but may allow dust and shreds of cotton to enter the solution.

Large flasks should not be sterilized with small bottles, as sterilization times depend on the size of the container and the volume of the fluid. Loads should be broken up, so that each load has approximately the same size of container.

At 248°F (120°C) the following sterilization times are recommended:—

2,000 c.c. flask (thick glass)	30 minutes
2,000 c.c. flask (thin glass)	20 minutes
1,000 c.c. flask (thick glass)	25 minutes
1,000 c.c. flask (thin glass)	20 minutes
500 c.c. flask (thick glass)	20 minutes
500 c.c. flask (thin glass)	15 minutes
250 c.c. flask (thin glass)	10 minutes
2 oz. bottle	10 minutes
1 oz. bottle	

CHAPTER 5.

STERILIZATION AND CARE OF SURGICAL INSTRUMENTS.

Selection of Instruments.

No instrument is better than the steel of which it is composed. Because of the superior qualities of certain alloys of stainless steel, the majority of modern surgical instruments are made from this metal. Some stainless steels are ductile; others are suitable for machining; some can be case hardened and forged; others weld easily—and any one instrument may be made of several types of stainless steel. The bright finish of stainless steel is due to a surface of chromic oxide which forms spontaneously whenever the old surface is destroyed. The term "stainless" is, however, only relative—there is no steel which is stainless under all conditions, and in surgical instruments it is more important to have the proper hardness and elasticity than to have an absolutely corrosion-proof alloy. Steels containing 12–17% chromium and 0·2–0·7% of carbon have been found most suitable.

For instruments, the tempering and workmanship are very important, and a reliable brand should be purchased. It is good practice to examine carefully all new instruments—the points of scissors and forceps should be equally long, the serrations of forceps should be even and should mesh properly, joints should not be too loose, and there should be no sharp points or edges that may catch the surgeon's gloves or cause unnecessary tissue trauma. All thumb and tissue forceps should be tested for tension.

Maintenance of Instruments.

Surgical instruments of good quality seldom wear out—the majority are rendered unserviceable by faulty cleaning, storage, sterilization, marking or handling. The proper care of instruments is well repaid, and attention should be given to the following points:—

(*a*) *Stiff joints.*—If the instrument is new, a little emery paste applied carefully to the region of the lock and worked in by opening and closing the instrument about a dozen times will generally suffice. If the stiffness is due to dirt or grease, a few drops of liquid soap (10%) in the joint or a few drops of detergent, followed by rinsing in water, may loosen it. If it is due to corrosion or mechanical damage, emery paste may be tried—if this does not succeed, the instrument should be sent to a firm which undertakes repair work.

(*b*) *Sharpening.*—Few hospitals have the facilities or a staff with sufficient experience to undertake the sharpening of cutting edge instruments. It is sound economy to have this done by a firm which specializes in the work. This does not apply to hollow needles which may be sharpened as described elsewhere.

(*c*) *Oiling.*—Oil should be used very sparingly on jointed instruments because a thin film of oil will retard sterilization, by concealing and protecting organisms so that moisture cannot reach them. If desired, a little 3-in-1 or other light oil may be applied and afterwards removed as completely as possible. Generally speaking, emery paste or liquid soap is to be preferred.

(*d*) *Prevention of Corrosion.*—Corrosion is the chief enemy of surgical instruments and it is well to understand how corrosion may occur.

In the case of nickel or chromium plated instruments, the steel is protected by a layer of chromium or nickel. The effectiveness of this coat does not depend on its high finish but on the presence or absence of microscopic breaks in the continuity of the layer. All electroplatings are rather porous, and corrosion of the underlying steel can occur between the particles of plating. These minute spaces are enlarged if the instrument is bent or warped, or if a name or a number is stamped on through the plating. Most of the corrosion is due to the dissociation of water into positive (H) and negative (OH) ions in the presence of dissolved oxygen, setting up electrolysis. The iron combines with the hydroxyl (OH) ions to form ferrous oxides ($Fe(OH)_2$). The hydrogen (H) ions either escape through the plating or form ferric hydroxide from the ferrous hydroxide. Thus ultimately ferric oxide—or common red rust—is formed on the surface.

Two types of corrosion destroy instruments. One is *atmospheric corrosion* which occurs when instruments are stored, particularly in humid air. Here oxygen enters through the pores, rust is deposited within or under the plating, and the protective coat is lifted off the underlying steel. This type of corrosion is ultimately very destructive. The other type is *immersion corrosion,* where rust accumulates on the surface particularly about hinges and serrations, in instruments that are immersed in the presence of a limited amount of dissolved oxygen. This is not so serious because very little damage occurs to the plating. It is not lifted up as in atmospheric corrosion.

Nickel plating probably forms the best protective coat, but it has the disadvantage of fogging easily, and of becoming tarnished if the atmosphere or water contains sulphur, especially in the presence of light. Chrome plating is less susceptible to tarnish, because a thin film of chromium oxide rapidly forms on the surface. Repeated scouring or rubbing away of this surface, however, will rapidly thin the layer of chromium. It is therefore common practice to give the steel a basic coat of copper or nickel (or both) before applying the layer of chromium. The undercoat protects against corrosion, whilst the thin layer of chromium can be given a high polish.

Shiny plated instruments have a good appearance, but the process of polishing and buffing removes a good deal of the chromium. ''Satin finish'' makes the most serviceable coating—in this process the chromium is deposited over a layer of nickel. Generally speaking, however, stainless steel is superior in utility to either nickel or chromium plating. Common substances that attack stainless steel are chlorine, ferric chloride, trichloracetic acid and mercuric chloride. Some users of stainless steel instruments have noted that rusting occurs, but this is usually at scattered points and is only surface deep—it usually is due to particles of steel from machine tools used in manufacture which have become embedded in the surface. Careful treatment during and after manufacture removes these inclusion particles.

Cleaning and Storage of Instruments.

Immediately after use all instruments should be dropped into a bowl or bucket of cold water to remove blood before it can dry and harden, the only precaution observed being that the instruments should be opened. It is advisable to add some lysol (about 2%) to the water as this aids removal of blood. If the water has a suitable detergent added, it may be warmed to about 140°F. Above this temperature albuminous substances (such as blood) will coagulate. The instruments are then dropped in boiling water to which 2% sodium carbonate has been added, and boiled for 15 minutes.

The final cleaning should be conducted with great care. It is most essential to remove all particles of adhering tissue, dried blood and scale or accumulations of lime salt in the serrations, ratchets and box locks of the instruments. A hand brush with fairly stiff bristles should be used, but the use of abrasives and soap powders should be avoided.

Immediately after cleaning, the instruments should be scalded with boiling soft water for a few minutes and dried thoroughly. Drying may be done with a soft towel but it is better to place the instruments in a cloth covered tray and dry them for a few hours in the autoclave. The autoclave should have steam circulating

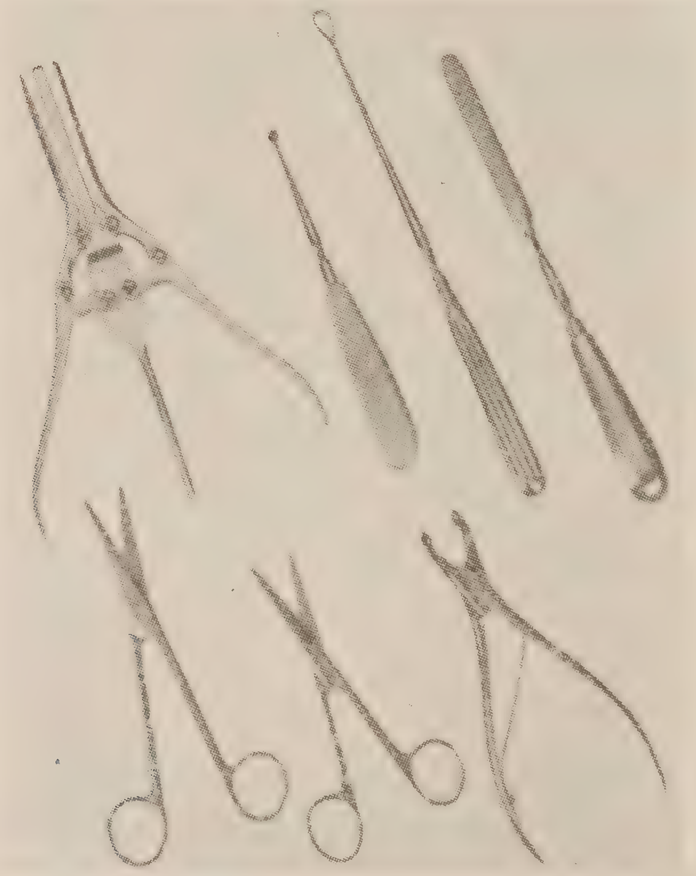

FIGURE 17.

These instruments are difficult to clean mechanically, and particular attention must be paid to serrations, joints, and depressions. If washed prompty after being soiled, cleaning will be much easier.

—*Courtesy American Sterilizer Company.*

in the jacket and the door may be left partly open. Alternatively, they may be dried in an oven. They should be stored in an enclosed cupboard containing calcium chloride or silica gel to dry the air.

Mechanical cleaning is a difficult process, but it must be thorough and should be done after every use. (See Figure 17.)

Sterilization of Instruments.

The selection of a method of sterilizing instruments demands serious consideration. In many hospitals, where surgical technique is otherwise of a high order, instruments are boiled for periods of from 10 to 20 minutes. Boiling is still the usual method of sterilizing instruments, but in the light of present knowledge, its safety is open to question. Many bacteriologists have demonstrated that spores will withstand boiling water for several hours. Yet frequently one sees a nurse or theatre attendant attempt to sterilize an urgently-required instrument by immersing it for a few minutes in boiling water. This practice is mentioned because it is so obviously unsafe and because it indicates a lack of knowledge of the principles of sterilization, both by the surgeon and by the theatre staff. Spores cannot be ignored and safety should never be sacrificed for speed. Steam sterilization has so many advantages over sterilization by boiling that it is the method of choice for the majority of surgical instruments. Because cutting instruments sometimes require different treatment from non-cutting instruments, a separate section is devoted to the sterilization of each group.

Sterilization of Non-Cutting Instruments.

1. Sterilization by autoclave.

Pressure steam sterilization of instruments can be accomplished in rather longer time but with greater safety than sterilization by boiling. This, together with the fact that all scale formation, spotting and corrosion is eliminated, makes autoclaving the method of choice. Autoclaving is suitable for all common metal instruments except perhaps von Graefe knives. Detachable scalpel blades rust quickly if autoclaved and hot air sterilization is preferable. Only the surface of the instrument requires sterilization, and a lethal temperature is quickly reached provided the instruments are mechanically clean. There is no need to allow a lag factor for penetration. Moisture condenses at once on the surface of the instruments, and the period of exposure need not be varied for light or heavy loads, if the instruments are arranged singly and do not lie in heaps.

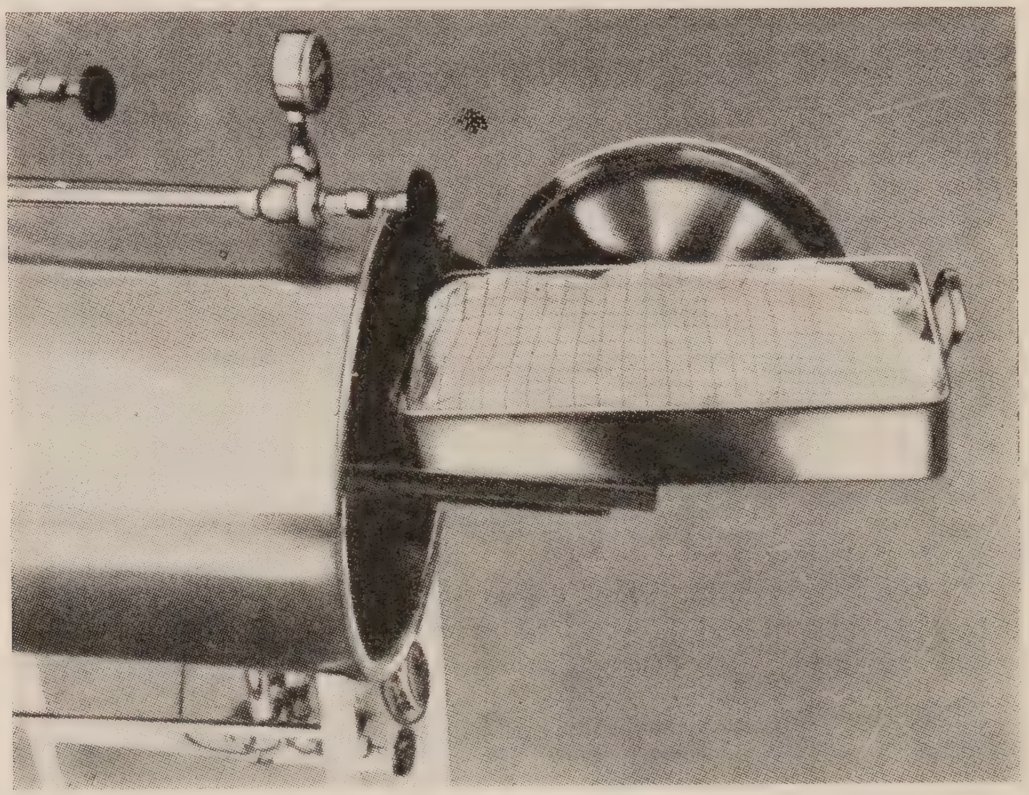

FIGURE 18.

When instruments are not to be used at once they may be covered with an additional towel to prevent contamination. Alternatively the whole tray may be wrapped in sheeting.

—Courtesy American Sterilizer Company.

If the instruments are not to be used for some time (up to 24 hours) after autoclaving, they should be arranged as described above, but the perforated tray should be covered with a double thickness of porous cloth, and the sterilizing time should be extended to 15 minutes (Figure 18).

If the instruments are to be used within a short time after sterilizing, the procedure is as follows:—Place a towel or muslin cover on the bottom of a perforated tray. Arrange the instruments on the cloth, one layer deep, and cover with a second towel or piece of muslin. (Figure 19.) Make sure that jointed instruments are open to permit prompt contact of steam to all surfaces. Place the heavier instruments (such as retractors) above, if necessary, and cover with another towel for protection against contamination whilst being carried into the theatre. Sterilize for 10 minutes after the thermometer records 248°F (120°C). There is no need to apply a vacuum at the end of this period, although this will accelerate drying. As an alternative, the door of the autoclave may be allowed to remain slightly open for about 10 minutes.

If the instruments are not clean, in the sense that the housewife uses the term, these sterilization times should be increased, as additional heat alone will not produce sterility. Time and moisture are the essential factors.

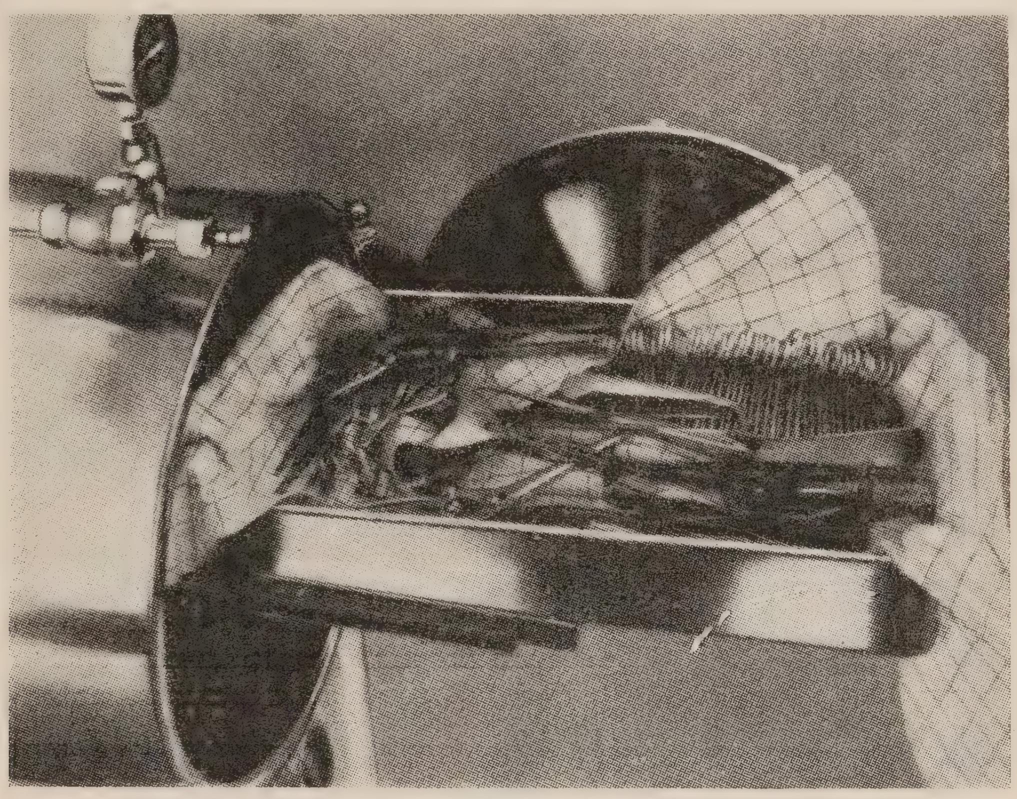

FIGURE 19.

Showing arrangement of instruments on a perforated tray. Instruments should be lightly packed and jointed instruments should be slightly opened out. A towel on the bottom of the tray affords protection for delicate instruments.

—Courtesy American Sterilizer Company.

2. Sterilization by Boiling.

The instruments should be mechanically clean, as described previously. As boiling water contains less dissolved oxygen, it is wise to drop the instruments or lower the tray full of instruments, directly into boiling water. Rain water or chemically soft water should be used as this will minimize the formation of scale.

The sporicidal effect of boiling water may be increased considerably by the addition of sufficient sodium carbonate (washing soda) to make a 2% solution, or by the addition of sodium hydroxide (caustic soda) so as to make a 0·1% solution, to the water in the sterilizer. These solutions also decrease corrosion of instruments, and will remove oily debris, but may make the instruments a darker colour.

Boiling water containing either of these alkalis in the concentration specified can be depended on to sterilize clean instruments in 15 minutes. Here again, care should be taken to see that all jointed instruments are open. All instruments, too, should be completely covered with water, and none should be wrapped in cloth or cotton wool.

The highest temperature that can be attained by boiling water is 100°C (212°F) at sea level. At higher altitudes the boiling point is reduced. For safety, the period of boiling should be increased by at least 5 minutes for every 1,000 feet elevation above sea level.

If instruments are sterilized by boiling it is important to remember the factors that will increase its effectiveness, viz.:—

(*a*) Use rain water or chemically softened water.
(*b*) Add 2% sodium carbonate or 0·1% sodium hydroxide to the water.
(*c*) Use sufficient water to keep every instrument totally immersed throughout the sterilizing period.
(*d*) Keep oil and grease out of the sterilizer. If a greasy scum forms on the sides of the sterilizer, remove it before the sterilizer is next used.
(*e*) Immerse the instruments in boiling water to reduce rust formation.
(*f*) Time the sterilizing period from the time the water boils.
(*g*) Sterilize for fifteen minutes by the clock, adding five minutes for every thousand feet of elevation above sea level.

3. Sterilization by Dry Heat.

Although it is not usual to sterilize non-cutting instruments in the hot air oven, they may be so treated. (See section below.)

Sterilization of Cutting Instruments.

The majority of cutting instruments can be effectively sterilized by autoclaving or by boiling. Some authorities maintain that the point or cutting edge is better preserved by sterilizing in the hot air oven. This is doubtful, except for such fine instruments as iridectomy knives and scissors. It is quite obvious, however, that a common method of sterilizing these instruments—viz., by immersion in chemical disinfectant solutions—is inadequate and unsafe.

(a) Sterilization by Dry Heat.

Scalpel blades, and needles (both suture and hypodermic) are preferably sterilized by hot air. Dry heat is difficult to control, and in an oven some parts are always hotter than others. Domestic ovens make reasonably satisfactory hot air sterilizers, provided they are fitted with an accurate thermometer and thermostat, but they tend to heat too rapidly. Rapid heating may cause breakages of glassware, and may also leave pockets of cool air surrounding articles. A properly designed hot air oven is better, and electrically-heated models are more satisfactory than those heated by gas or other fuel.

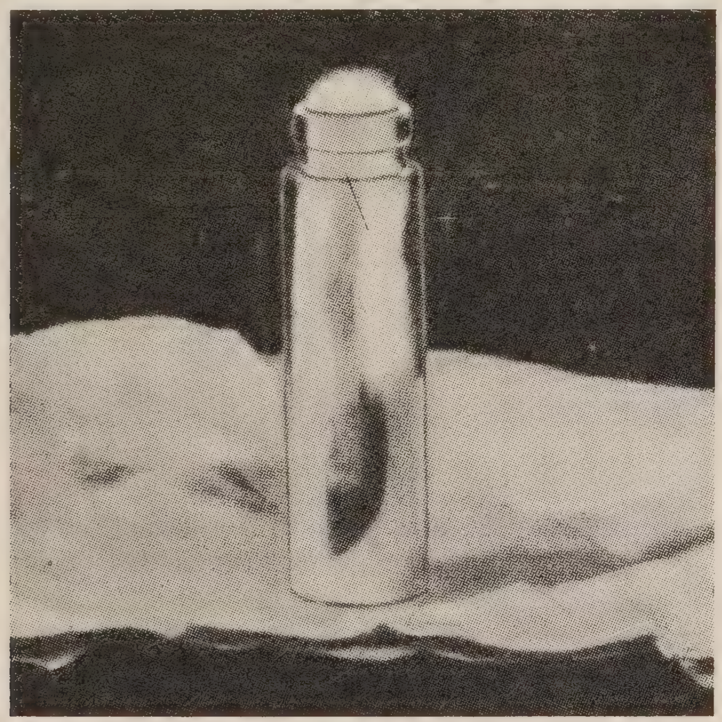

FIGURE 20.

Showing a scalpel blade in a small medicine bottle. To prevent damage, cotton wool is placed at the bottom of the bottle, and is loosely wrapped around the blade. The top of the bottle is lightly plugged with cotton wool. Scalpel blades are best sterilized by dry heat, but this bottle may also be autoclaved if laid on its side.

—Courtesy American Sterilizer Company.

Scalpel blades should be placed individually in a small tube or medicine bottle, with only a wisp of cotton wool or gauze to protect the blade from the sides. A light plug of cotton wool closes the opening and, if desired, the glass container may be wrapped in one or two thicknesses of gauze or cotton (Figure 20). These can only be sterilized once.

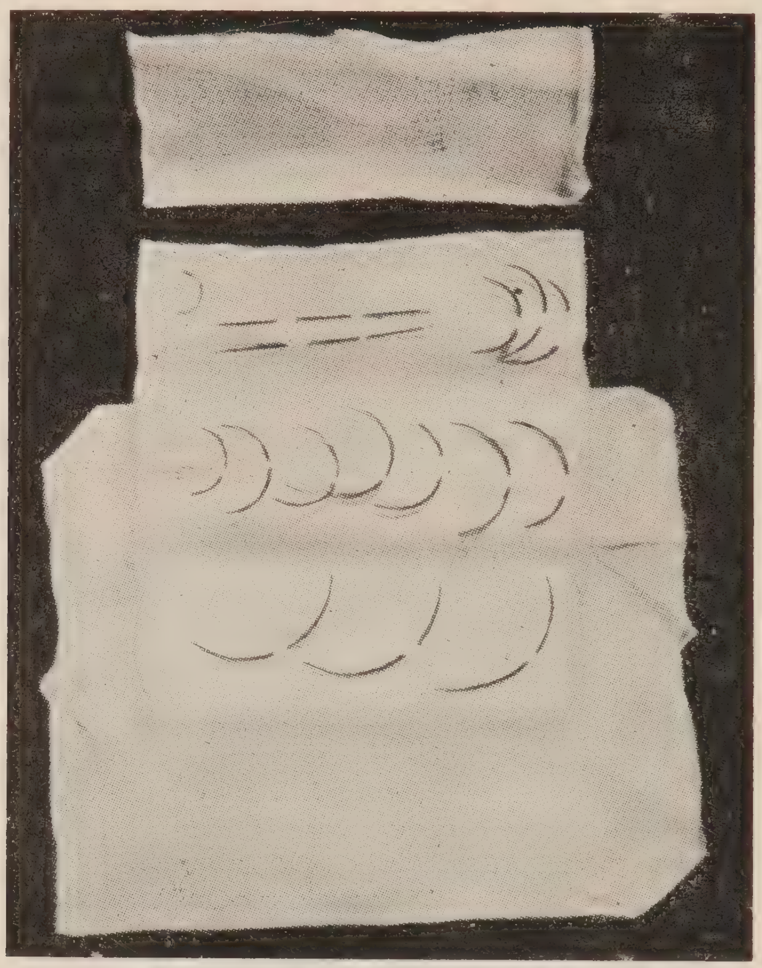

FIGURE 21.

Suture needles may be sterilized by threading through a gauze pad. They are then lightly wrapped in muslin and sterilized by hot air or by autoclaving.

—Courtesy American Sterilizer Company.

Suture needles may be placed in a petri dish or threaded through a gauze pack and wrapped in a layer or two of cotton material (see Figure 21).

When sterilized in the hot air oven, all cutting instruments should be sterilized for one hour at 320°F (160°C). Sterilization should be timed to commence when the internal temperature reaches 320°F. It is not wise to exceed this temperature, as charring of cotton wool occurs at approximately 174°C (345°F) and the temper of certain instruments may be adversely affected.

All instruments sterilized by hot air must be clean and free from grease as sterilization of dirty instruments is always uncertain.

CHAPTER 6.

STERILIZATION AND CARE OF SYRINGES AND NEEDLES.

When is a Syringe sterile?

The common methods of attempting to obtain sterility of a syringe are by boiling in water or by immersion in a disinfectant solution. The widespread use of chemical disinfectants for this purpose is disquieting, for no chemical solution will destroy spores with certainty. Boiling water will destroy vegetative bacteria, but will not certainly kill spores. A boiled syringe, therefore, if it were cleaned beforehand, can be regarded as reasonably safe though it should not be regarded as sterile.

Sterility can only be achieved by exposure to moist heat or hot air at the correct temperatures for certain stated periods of time.

Selection of Syringes.

Three types of syringe are the all-glass syringe, the all-glass syringe with a metal tip, and the glass and metal syringe. The fitting may be either of the Record type or the Luer type.

An all-glass syringe is easier to clean and sterilize and is less liable to fracture than the glass and metal type, though the latter is cheaper. All-glass syringes can also be assembled prior to sterilization, and do not become loose as easily as the glass and metal syringe—so that very little, if any, of the substance being injected escapes past the plunger.

However, all-glass syringes do have an important disadvantage in that the nozzle is fragile and easily chipped or broken. This is overcome by fitting a metal nozzle to the barrel with a high melting point cement. Microscopic cracks tend to form in any cement after a time thereby enabling organisms to gain entry, and making sterilization rather more difficult.

A decision as to whether the Record or Luer type nozzle should be purchased depends on the hospital. Hitherto all Luer fitting syringes were American made but this type of fitting is now being made in England so it is likely that Luer type syringes will shortly be more freely available than at present. Luer fitting prevents the needle from slipping, and is therefore more satisfactory than the Record fitting.

To summarize, it would appear that hospitals should gradually increase their stocks of all-glass syringes fitted with metal nozzles. As all-glass syringes with Luer fittings become available, these should become the standard hospital syringe.

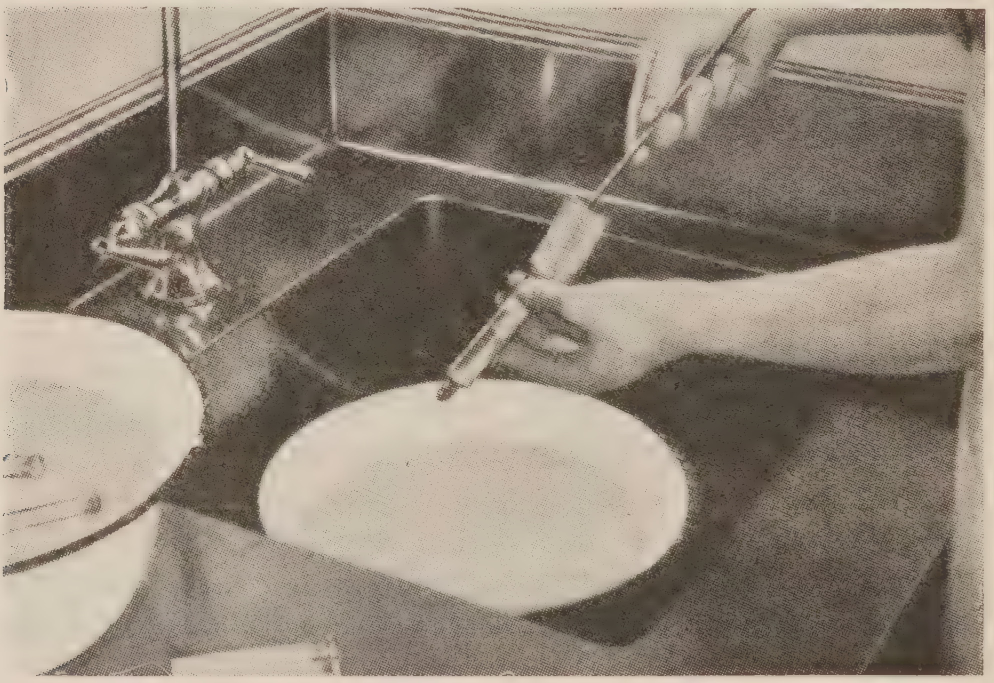

FIGURE 22.

Syringes require thorough cleaning after use and before sterilization. Warm water and soap or warm water containing a detergent is required, as well as a circular brush of appropriate size. Attention should also be paid to the hub of hollow needles where the needle joins the barrel.

—*Courtesy Becton, Dickinson & Co.*

Cleaning of Syringes.

New Syringes.—These should be washed in warm soapy water using a stiff circular brush (see Figure 22). They are then rinsed in clean water, and if stiff, a little glycerin or liquid paraffin is rubbed well into the plunger with the finger. Surplus paraffin or glycerin is removed carefully with a cloth and the syringe assembled. If barrels and plungers have no serial number, they should be marked with an identical number.

Used Syringes.—Syringes which have held blood, pus or biological products such as anti-sera, should be rinsed immediately in 2% lysol or in an organic detergent solution. The fluid should be sucked up and expelled several times with the needle still attached. The syringe is then rinsed with cold water. Syringes used for any other purpose should be rinsed in cold water as above.

Before being sterilized, syringes should be thoroughly cleaned in warm water and soap, or in detergent solution, using a circular brush, then rinsed in clean water and assembled after matching barrel and plunger.

Syringes washed in detergent solutions should later be rinsed a dozen times in clean soft water otherwise haemolysis is likely to occur in blood withdrawn by venipuncture.

Sticking Syringes.—Failure to clean a syringe immediately may result in the plunger sticking in the barrel. Various techniques have been developed to free syringes of which the following are the most useful:—

(1) Place the syringe in ice water or in a freezing compartment for 10 minutes, then immerse the barrel, up to the flange, in hot water for a few seconds. The contracted plunger can often be removed from the expanded barrel.

(2) Boil the syringe for 10 minutes in a mixture of 25% glycerine and 75% water, and attempt to remove plunger while still hot.

(3) For Luer fitting syringes, all metal syringe openers may be obtained. The syringe is placed in ice or in the coldest part of a refrigerator for 10 minutes, then the all-metal syringe opener is filled with warm water and attached to the nozzle of the blocked syringe. Steady firm pressure is applied until the water infiltrates between the barrel and the plunger, and shortly after the plunger will be expelled from the syringe. A towel spread beneath the syringe will prevent breakage of the plunger.

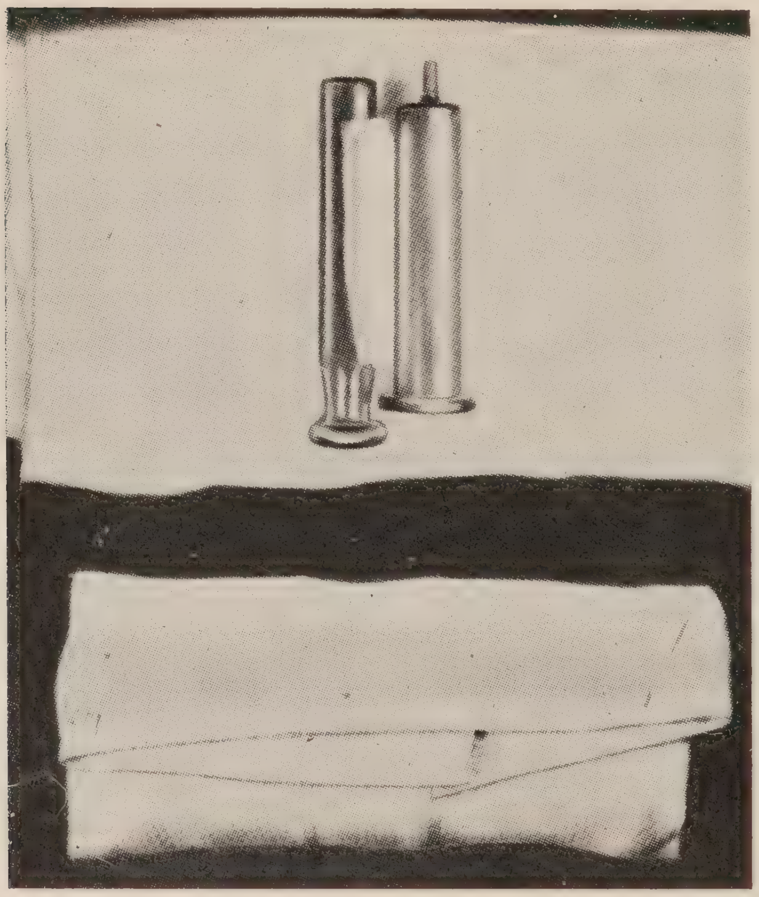

FIGURE 23.

A satisfactory method of preparing syringes for sterilization. The syringe is disassembled, and the two parts are wrapped in a towel with a gauze pad between plunger and barrel to prevent chipping. The towel is then folded and pinned. Syringes wrapped like this may be sterilized by moist or dry heat.

—Courtesy American Sterilizer Company.

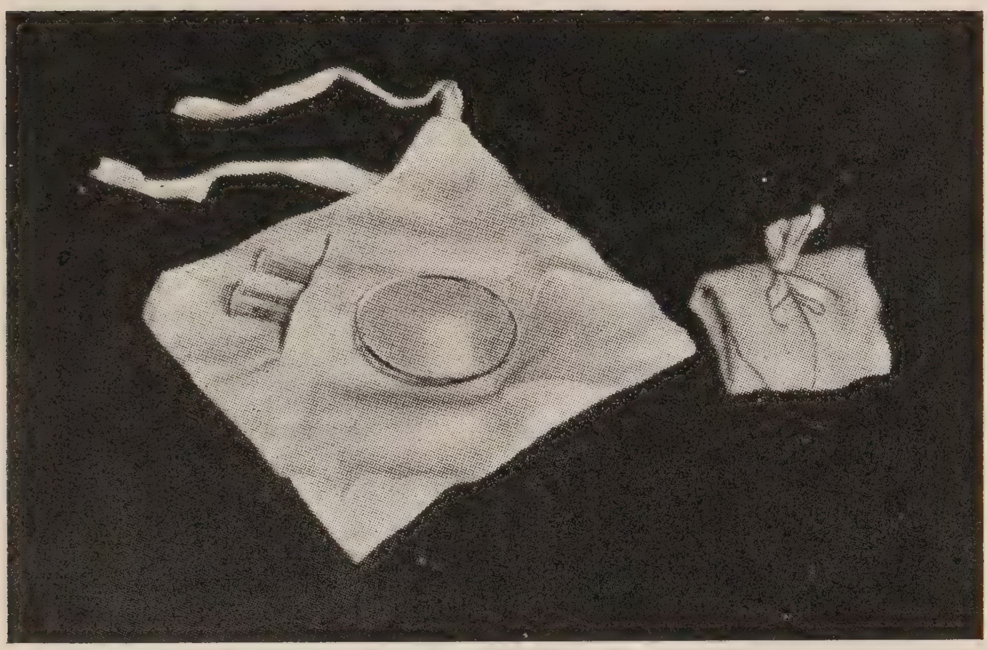

FIGURE 24.

If desired, special syringe covers may be made as above, with separate pockets for piston and barrel. The watch glass is useful for dissolving hypodermic tablets.

—Courtesy American Sterilizer Company.

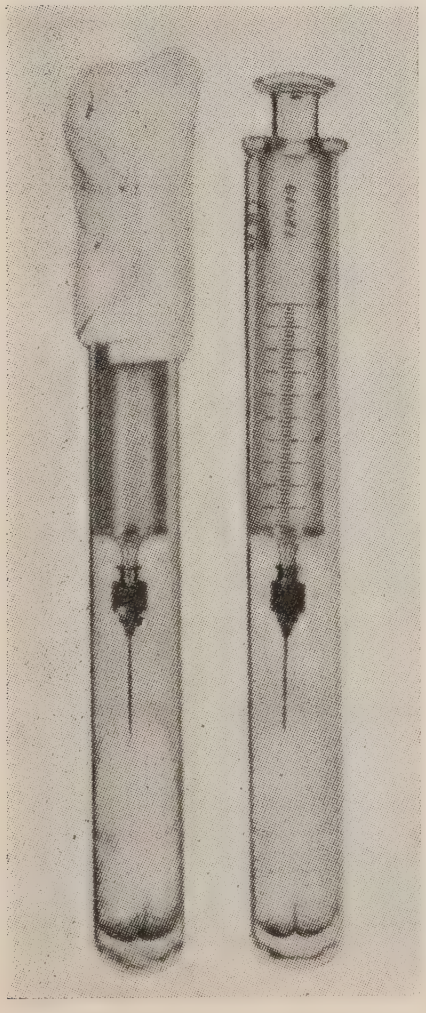

FIGURE 25.

All-glass syringes, completely assembled, may be sterilized by hot air, if placed in a tube of such diameter that the flange of the syringe rests on the top of the tube. Cotton wool is placed at the bottom of the tube, and the top of the tube may be protected with a cotton cover.

—Courtesy American Sterilizer Company.

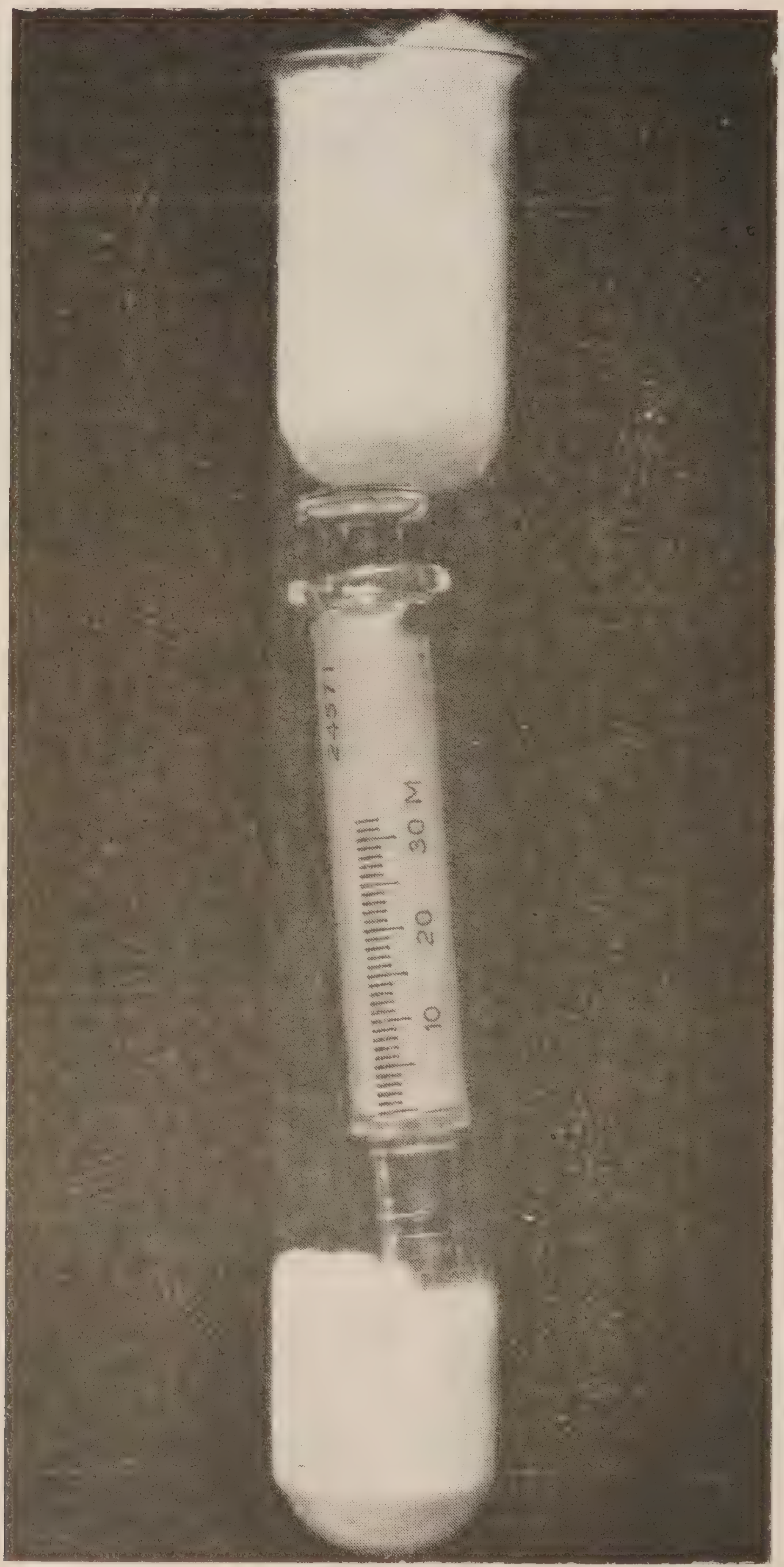

FIGURE 26.
All-glass syringes may be completely enclosed in a large test tube or cylinder as illustrated, and sterilized by dry heat.

Packing of Syringes for Sterilization.

If the syringe is to be sterilized dismantled—and this applies particularly to glass and metal syringes—it should be wrapped in a cotton cover, with the top of the plunger and the top of the barrel lying the same way, and the cover is then pinned (see Figure 23). If desired, a special syringe cover can be made, with separate pockets for the barrel and plunger (Figure 24).

If the syringe is assembled before sterilization, the most convenient container is a tube of such diameter that the flange of the syringe rests on the top of the tube (Figure 25). Alternatively, the syringe may be placed in a large test tube or jar so that the whole syringe is within the tube (Figure 26). In either case the needle may be attached to the syringe if there is a layer of cotton wool at the bottom of the tube. A cotton cover is tied over the top of the tube, or if the syringe is entirely within the tube, the top may be lightly plugged with cotton wool. Barrel fractures are rather more frequent if the syringes are sterilized assembled.

A watch glass can be sterilized in the syringe wrapper. It is useful for dissolving hypodermic tablets in water.

Sterilization of Syringes.

If Australian-made Record syringes are used, only those with 200°C marked on the barrel can be heat-sterilized. Unmarked Australian-made syringes have a low melting point cement that will run when heated.

(*a*) *Sterilization by Hot Air.*—Assembled or unassembled syringes can be sterilized in the hot air oven at 160°C for not less than one hour. The timing of sterilization is from the time when the thermometer records 160°C. Syringes should be placed in and taken out of the oven only when it is cool, otherwise breakages will be excessive.

(*b*) *Sterilization by Autoclaving.*—Unassembled or assembled syringes may be autoclaved at 120°C for 15 minutes or longer.

(*c*) *Sterilization by Pressure Cooker.*—Syringes, either wrapped or unwrapped, may be sterilized in a reliable pressure cooker for 15 minutes after the safety-valve starts to blow steam. Pressure gauges on cookers are apt to be unreliable, and in any pressure cooker it is advisable to place a benzoic acid-methylene blue testing tube in the cooker from time to time to ensure that a temperature of 120°C has been reached. For further information see section on pressure cookers, page 74.

(*d*) *Sterilization by Boiling.*—This can be achieved with reasonable certainty only if acid or alkali is added to the water to destroy spores; 1-2% solution of cresol with soap (lysol) is recommended, because alkali attacks the glass. However, it should be remembered that lysol in water is alkaline in reaction; 1% or 2% lysol has a pH of about 8·2 in distilled water so that if the surface of the syringe becomes pitted and scored its use should be abandoned. Any acid solution (1% liquified phenol, 1% acetic, 1% hydrochloric) is effective against spores, and probably would prove equally as satisfactory as lysol, but these may also cause corrosion of the glass.

The syringe must be clean and should not be wrapped in cloth or cotton wool; the water should be soft otherwise scale or chalky material will be deposited on the glass, and this will cause scoring and scratching. If chalky deposits form they may be removed by soaking in weak hydrochloric acid. Syringes should not be placed in very hot water otherwise they may crack.

Boil for 10 minutes, allow to cool and dry, and then assemble with sterile forceps. If lysol or acid has been added to the water these substances may react with the medicament to be injected, therefore the assembled syringe should be filled with sterile saline and the saline expelled. This should be repeated several times. For this purpose, small (1 oz.) bottles of sterile saline should be available. The bottle is discarded after the syringe has been rinsed.

Disinfection of Syringes.

(*a*) *Disinfection by Boiling.*—A syringe that has been boiled for 10 minutes in rain-water or other soft water can be regarded as reasonably safe even if not sterile.

The same precautions should be observed as in boiling with lysol or acid. The syringe should be dismantled, cleaned, and should not be wrapped, as lint or cotton wool prevents drying and may also prevent the syringe from reaching the boiling point of water.

Boil for 10 minutes, then allow to dry before assembling with sterile forceps.

(*b*) *Disinfection by Chemicals.*—This is justifiable only when syringes are used exclusively for the injection of a sterile fluid (e.g. insulin) in circumstances where heat sterilization is impracticable. The common practice of attempting to disinfect a syringe by filling it with disinfectant and then discharging is useless and may be dangerous.

The only disinfectant that can in any way be recommended is 70-75% V/V alcohol. Only all-glass syringes should be used. The syringe is washed in tap water, using a brush. The needle is attached, and the alcohol is sucked up and down several times. The syringe is then dismantled and completely immersed in the spirit, in a covered vessel, for at least five minutes. The syringe is then assembled by clean or sterile forceps, excess alcohol is shaken off, and the syringe with needle attached is placed in a covered container until it is next used. If desired it can be rinsed with sterile water. Syringes used regularly in this way should be sterilized periodically by hot air, autoclave or pressure cooker.

Syringes and Needles for Mass Inoculations.

Syringes used for mass inoculations are best sterilized in the hot air oven or autoclave. If these are not available, syringes (assembled or unassembled) should be placed in a reliable pressure cooker and sterilized for 20 minutes at 248°F.

Needles should be treated in a similar manner. However, if they are sterilized prior to commencing the inoculations it is unlikely that they will become contaminated with spore-forming organisms within the short period during which the inoculations are being given. It is therefore justifiable to disinfect the used needles by boiling for ten minutes or by leaving them in a pressure cooker for five minutes after the safety valve starts to blow.

Recently it has been shown that when a needle used for inoculation is removed from a syringe negative pressure is created inside the lumen which may result in material which has been in contact with human tissues being drawn back into the nozzle of the syringe. When the syringe is next used with a new needle, transference of this material to another person could occur. In this way it might be possible to transfer infection (such as virus hepatitis) from one patient to another. Although the risk of transmitting infection is very small, if practical measures will avoid it they should be used.

One method would be to use platinum needles which can be heated in a flame. Another way would be to use a separate needle and syringe for each injection. In some instances, however, these measures may be impractical.

Two other methods may be used. The first method is to give the measured dose, withdraw the needle (holding the piston firm) and then expel sufficient of the contents from the syringe to ensure that the lumen of the needle is filled with contents that have not been in contact with the tissues of the previous patient. The needle is then removed, and a new needle fitted before giving the next injection.

The second measure is that adopted for years at St. Mary's Hospital, London. Instead of removing the needle, it is dipped for about ten seconds (or longer) in a bath of paraffin oil, maintained at a temperature of 150°-160°C. The water in the needle quickly boils and vegetative pathogenic organisms or viruses are thereby destroyed. The same needle can then be used for the next patient.

Mass Intravenous Injections.

A separate syringe and needle are needed for each injection. Sterilization by hot air is the method of choice but autoclaving is satisfactory. Failing these, the syringes should be rinsed with cold 2% lysol, washed in warm soapy water, rinsed in clean water, boiled and finally rinsed in sterile saline.

Syringe Service for Large Hospitals.

Such a service is efficient and satisfactory, and keeps down breakages. A standard all-glass syringe is adopted, and the service (in charge of a trained nurse or qualified technician) takes care of all syringes and needles and sees that they are adequately sterilized. The sterilized syringes and needles are issued to wards on demand, and syringes, after use, are washed clean in the wards.

Use of Syringes for Certain Special Purposes.

Tuberculin.—Should be used for no other purpose, or spurious positives will result.

Aspiration.—Should be kept separate, where possible.

Insulin
Adrenalin

Spirit disinfection customary, if used by one person only.

Syringe should be periodically sterilized by one of the methods outlined earlier in this chapter.

Before handling a syringe, the hands should be washed and dried thoroughly. When assembling a syringe, avoid talking, sneezing or coughing. Syringes, if wet, should be assembled only with sterile forceps.

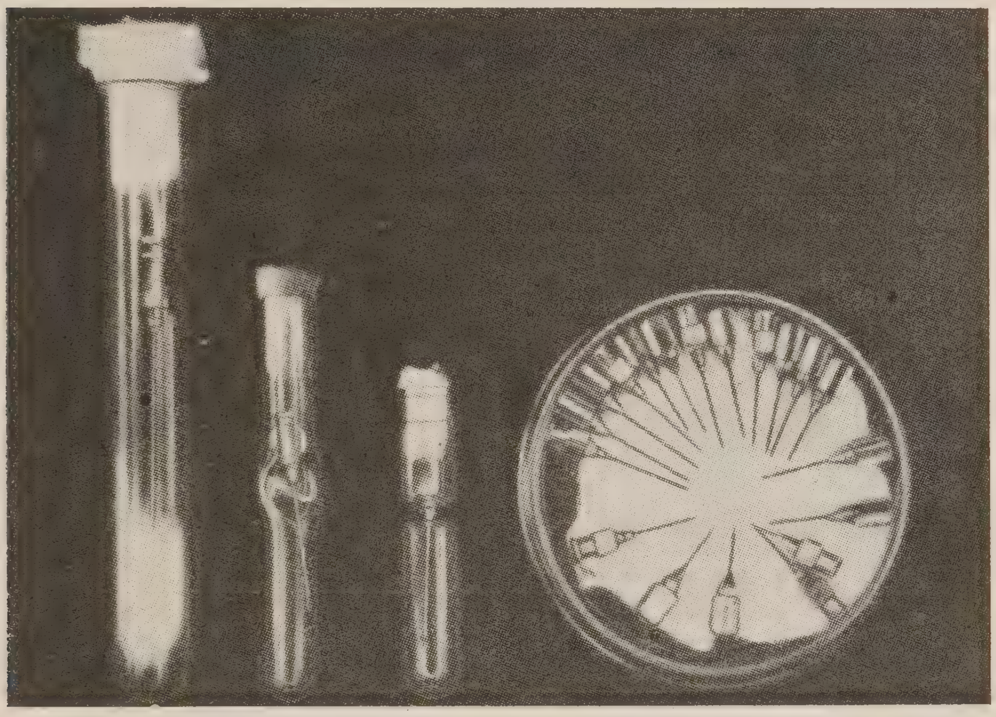

FIGURE 27.

Methods of preparing hollow needles for sterilization. At the left is a test tube, with top and bottom plugged with cotton wool. In the centre are serum tubes with a constriction on the sides to prevent the needle touching the bottom—these constrictions can be made with a bunsen flame. At the right is a petri dish containing needles resting on a piece of lint. The needles may be threaded through the lint to prevent rolling. A piece of cellophane tape over the petri dish keeps the two parts together.

—Courtesy American Sterilizer Company.

Disinfection of Vials.

Vials with rubber tops should be protected from dust by a metal or plastic top and kept in a cupboard or refrigerator. Before use, the rubber cap is wiped with sterile lint or cotton wool soaked in 70-75% V/V alcohol.

Skin should be wiped with the same solution or with weak solution of iodine (B.P.). The disinfectant should dry before the injection is made.

Sterilization of Hollow Needles.

Sterilization in the hot air oven at 160°C for at least one hour and preferably two hours is the method of choice. Individual needles may be placed in small tubes with or without restricted sides. If the sides are restricted it is not necessary to place a plug of cotton wool at the bottom of the tube to prevent damage of the point. Where a large number of needles may be required, as for ward use or mass inoculations, they may be placed in a petri dish, the bottom of which is covered with a piece of lint (Figure 27). Needles may be threaded through the lint to prevent movement. Before sterilization, removal of stylets is advised to prevent corrosion by electrolytic action between the stylet and the needle.

Needles may also be autoclaved with the syringe.

Alternatively and less satisfactorily, needles can be boiled, but immersion in germicidal solutions is not recommended.

Care of Hollow Needles.

Every hospital should keep its hollow needles sharp and bright. The care of needles begins in the ward and nurses should be instructed in the care of both syringes and needles.

The most common trouble with needles is plugging of the lumen with blood, grease or dirt. Needles should be cleaned as soon as they are used by rinsing in cold water, or in 2% lysol if the syringe and needle have contained blood. Prior to sterilization, needles should be thoroughly cleaned. Hot detergent solution will help, but attention should be paid to cleaning out the hub of the needle where it joins the barrel of the syringe. Hot solution should be blown through the needle and a snug-fitting stylet inserted.

Needles should be inspected for weakness where the cannula joins the hub. This can be tested for by springing the tip of the needle with the finger while holding the hub firm. Weak needles bend or break, and should be discarded.

Needles can easily be kept bright and sharp. Place a little jeweller's rouge on the needle and rub when dry. This will restore the polish.

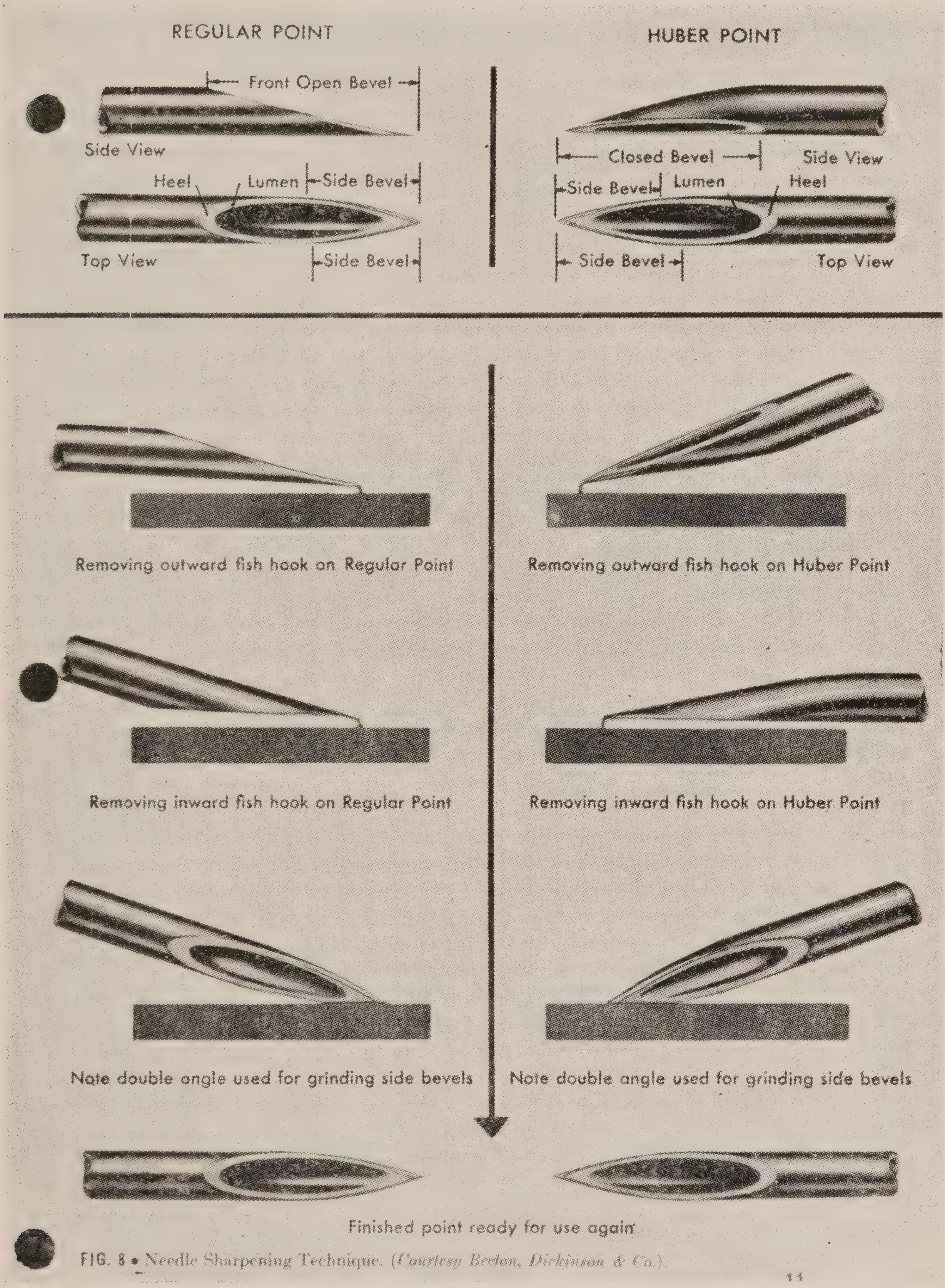
REGULAR POINT
Front Open Bevel
Side View
Heel
Lumen
Side Bevel
Top View
Side Bevel
HUBER POINT
Closed Bevel
Side View
Side Bevel
Lumen
Heel
Side Bevel
Top View
Removing outward fish hook on Regular Point
Removing outward fish hook on Huber Point
Removing inward fish hook on Regular Point
Removing inward fish hook on Huber Point
Note double angle used for grinding side bevels
Note double angle used for grinding side bevels
Finished point ready for use again

FIG. 8 • Needle Sharpening Technique. (*Courtesy Becton, Dickinson & Co.*)

FIGURE 28.
Needle sharpening technique.

—*Courtesy Becton, Dickinson & Co.*

Sharpening is more difficult. Hooked or blunt tips are the common cause of blunt needles. It is necessary to have a coarse carborundum stone, a fine Arkansas slipstone, a needle adapter fitted with a handle to hold the needle, a magnifying lens, and some light mineral oil. The first step is to grind off any hook at the tip of the needle, and the coarse stone will do this quickly. Next the bevel must be restored and sharpened on the fine stone, and this will require several inspections with the lens. Oil should be used, the bevel should be laid flat and movement of the needle should be elliptical. The bevel should be smooth and shiny. Finally, the sides of the bevelled point are rubbed on the stone until the needle will penetrate skin easily. In the case of lumbar puncture and artificial pneumothorax needles, the stylet must be kept in during sharpening so that both stylet and needle, or trochar and cannula, are ground down at the same time (Figure 28).

For large hospitals an electric needle sharpener is recommended.

Finally, in sterilizing needles, every care should be taken to protect the points.

CHAPTER 7.

STERILIZATION OF MISCELLANEOUS ITEMS.

Sterilization of Suture Materials.

Catgut.—No hospital can safely sterilize its own catgut. All catgut sutures should be purchased in tubes, already sterilized, from reliable manufacturers. The sterilization of catgut is an elaborate process, involving temperatures of up to 165°C for as long as five hours, and is performed after the catgut has been polished, wound on reels and placed in glass tubes containing anhydrous fluid such as cumol, naphtha, xylene or toluene.

Tubes containing boilable gut are not opened again, and the tubing fluid is therefore anhydrous. The sutures are stiff and wiry when removed from these tubes, and the catgut must be placed in 70% alcohol, or better still in sterile saline, to restore its pliability. The only advantage of the boilable gut is that the exterior of the tube can be sterilized by boiling or by autoclaving with the instruments. Tubes can also be disinfected as are tubes of non-boilable gut.

Non-boilable catgut, on the other hand, has the original anhydrous fluid drained off after sterilization, and replaced by a tubing fluid containing some water—a common one is 95% alcohol. The catgut absorbs water, making it soft and supple when removed from the tube. Tubes containing non-boilable gut cannot be heated, and the exterior of the tube must be disinfected by immersion in 1-100 Zephiran (coloured) in 70% alcohol, or in coloured formaldehyde alcohol coloured with 0·05% erythrosine. These solutions have a low specific gravity and the tubes should sink.

Any unused catgut must be discarded.

Horsehair.—Horsehair is so frequently contaminated by spores that it should be purchased ready sterilized in tubes containing anhydrous fluid. The manufacturers subject the horsehair to dryheat sterilization.

Nylon (Monofilament or braided).—This can be safely sterilized with the instruments, i.e., at 120°C for 15 minutes in an autoclave, either in loose coils or loosely wrapped on a metal or glass spool. One manufacturer of nylon sutures recommends that sutures be placed in a container and autoclaved in aqueous solution for 30 minutes.

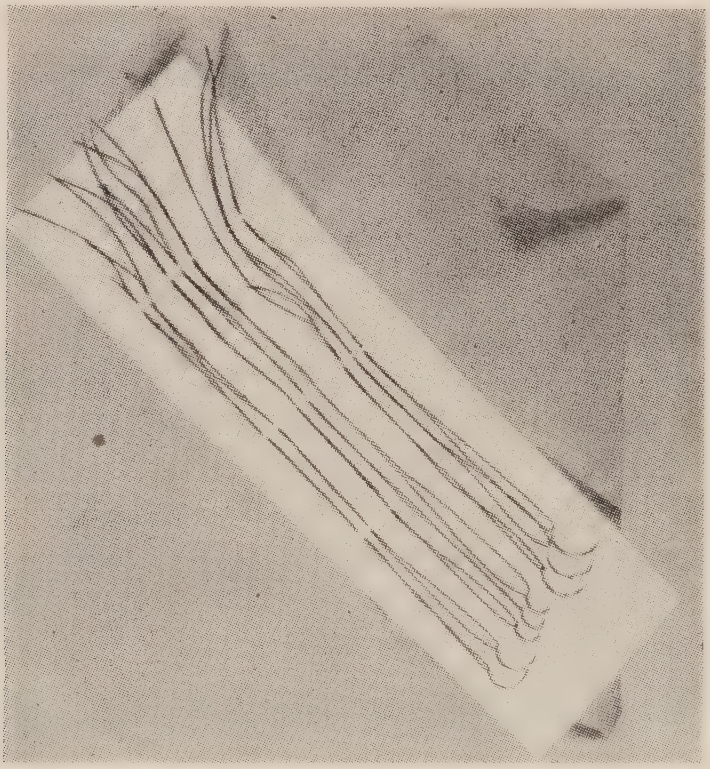

FIGURE 29.

Fine sutures of nylon and silk may be threaded on needles and basted through a gauze pad. The gauze is lightly rolled before sterlization.

—*Courtesy American Sterilizer Company.*

Silk.—Most silk sutures are in the form of braided silk which has been waxed by the manufacturer to stiffen and lubricate it. If sold in tubes, only the outside of the tube requires disinfection. If sold in reels or coils, it should be sterilized by autoclaving at 120°C for 30 minutes, or if unwaxed at 120°C for 15 minutes. The silk should be loosely wound on reels or spools, as a certain amount of shrinkage may occur. Do not sterilize more than three times.

Cotton.—If sterilized on the reel, there is a serious loss of tensile strength due to stress from shrinkage. It should be made into coils, or else wrapped around rubber tubing or a gauze pad which will allow it to shrink. The tubing may be wrapped in a cotton cloth. Sterilize for 15 minutes at 120°C in an autoclave.

Silkworm Gut.—If silkworm gut is autoclaved, it will be too stiff, but it will be soft if autoclaved while submerged in water in a container. Sterilize for 30 minutes at 120°C.

Tantalum.—These sutures may be autoclaved with the instruments.

Kangaroo Tendon.—Purchase these sutures ready sterilized from a reliable manufacturer.

Fine sutures of nylon, cotton or silk can be threaded on to needles, and then basted through gauze. The gauze is lightly rolled before being placed in the autoclave. (Figure 29.)

Sterilization of Water.

A distinction should be drawn between sterile distilled water and sterile tap water—the latter contains minerals, dead organisms and pyrogens, and thus is quite unsuitable for parenteral use.

Tap water is not difficult to sterilize. If the source is from the public supply, it usually has a low bacterial count and the few bacteria present are non-pathogenic.

Heating in the hospital type water "sterilizer" will render it safe for external use, although it is obviously undesirable for swabs and towels to be rinsed in this water before being used in the peritoneal cavity. Sterile distilled water should be used for this purpose.

The difficulty with the hospital "sterilizer" is to keep the water sterile after it has been boiled. The sources of contamination are as follows:

(1) Water contains dissolved air which is driven off as the water is brought to boiling point. As the water cools, air is again absorbed—this is referred to as "breathing." If the air contains organisms these are likely to be introduced into the cooling water. Many sterilizers have no filter for this incoming air, others have filters which are ineffective or which quickly become ineffective. Several layers of sterile gauze tied over the air inlet will prevent some contamination provided the filter is renewed immediately after every heating.

(2) The water "sterilizer" is filled from a tap, usually controlled by an external valve. After a time most taps develop a slow leak and unheated water can contaminate the reservoir.

(3) The water-level indicator is usually a glass tube, and the water in the indicator does not circulate, and does not boil when the tank is heated.

(4) It is very difficult indeed to keep the outlet tap sterile, unless it is flamed with a blow-lamp. Slime and other debris tend to form inside the tap and are not removed by flushing the tap each time water is required.

(5) If the water tank contains a coil through which cold water circulates to cool the water in the tank, a leak may develop in the coil.

Many different types of water "sterilizer" have been developed to overcome these defects, but none is entirely successful. Sterility of the water can never be relied on—the only safe water is water that has been autoclaved. Water "sterilizers" are ineffective—this should be recognised, though very few infections are due to water that comes from a public supply. Water boiled in an urn and used as soon as it is cool is more reliable than water from one of these so-called "sterilizers."

Glove Powder.—Powder used for surgical gloves is either starch powder (B.P.), specially prepared starch powder, or talcum powder.

Talcum powder occasionally contains tetanus spores and, in addition, will cause talc granulomas, particularly in the peritoneal cavity, if it gains entrance through a perforation in the gloves. Its use for surgical gloves is not recommended.

Specially prepared starch powders, of which there are several proprietary brands on the Australian market, are stated to have been processed to prevent "gelling" when the product is autoclaved. The value of this treatment is questionable, because powders of any kind should not be autoclaved if dry heat sterilization is available. Starch powder may also contain tetanus spores.

Starch powder (B.P.) is a fairly satisfactory substitute, particularly if 1%-2% light magnesium carbonate is added. However, the addition of mineral salts to the powder is not encouraged as there is some evidence that they may stimulate granuloma formation.

Starch or talcum powder may be sterilized by using either of the methods outlined below.

Method A.—About a level tablespoonful of the powder is placed in an ointment jar, about 1½ inches in diameter, the screw lid of which has been perforated so that the container can be used as a sprinkler. The jar is wrapped in paper, sealed with plastic tape or thread, and placed in a domestic oven, which has been heated. When the temperature of the oven reaches 500°F, the heat is turned off, and the oven is kept closed for two hours, during which time the temperature of a well insulated oven will be found to have dropped to about 400°F. The jars are then removed, and are stored until used in the theatre. The contents of a jar contain sufficient powder for four pairs of gloves.

Method B.—Sufficient powder is spread on the bottom of a glass petri dish to form an even layer not greater than one-quarter of an inch in thickness. Several petri dishes can be prepared and sealed with a strip of plastic tape. They are placed in a laboratory-type hot-air oven, taking care not to tilt the dishes. For each dish, an empty sprinkler-top container should also be placed in the oven, and a glass funnel should be included. The load is kept at 160°C (320°F) for not less than two hours. The powder, sprinkler containers and funnel are placed in a sealed cupboard until just before use, when the powder can be transferred to the container. Not more than a week's supply should be sterilized at one time.

Starch powder turns a light brown colour after dry heat sterilization, but its lubricating qualities are not impaired.

If it is desired to autoclave glove powder, because no method of hot air sterilization is available, a little powder should be rubbed evenly over the inverted surfaces of the gloves. The gloves are then everted, and autoclaved for 15 minutes at 120°C. Sufficient powder remains on the gloves to enable them to be slipped on readily,. but sterilization of the powder cannot be guaranteed.

Sulphanilamide Powder.—Sulphanilamide has a melting point of 165°C, but other sulpha derivatives have rather higher melting points. Nevertheless, care must be taken not to exceed 160°C in the oven.

Sterilization is the same as for talc powder. If desired, a small quantity can be sterilized in a test tube, if the diameter of the test tube is ¾ inch-1 inch, and the depth of powder does not exceed ½ inch.

Plaster of Paris.—In recent years tetanus spores have been found to be present in certain batches of plaster of Paris, thereby creating risk of infection, when plaster is applied directly over open wounds.

Sterilization of plaster of Paris presents a difficult problem. Moist heat is obviously impossible, whilst dry heat at 160°C causes deterioration of the plaster. Chemical methods involving the use of formaldehyde gas or ethylene dioxide at reduced atmospheric pressure have been devised and found effective, but these methods are too elaborate for the average hospital. It is likely that manufacturers will take steps to ensure that plaster of Paris products used for compound fractures or for covering wounds are free from spores, and, if so, the slight hazard of tetanus from this source will be eliminated.

Various Oils and Greases.—The slow rate of heating seen when powders are placed in the hot air oven is even more marked in the case of oils and greases. For example, a four-ounce jar of petroleum jelly placed in the hot air oven takes almost three hours to reach 160°C from room temperature, whereas the oven attains this temperature in about an hour. If the exposure period of two hours is added, almost five hours will be required for proper sterilization.

It is therefore not advisable to sterilize petroleum jelly in jars or ointment pots, unless these are only part filled. It is recommended that about 1½ ounces of petroleum jelly be placed in a petri dish of 4 inch-5 inch diameter, so that when melted the thickness of the layer does not exceed ½ inch. This should be sterilized for at least two hours after the hot air oven records 160°C.

If it is desired to sterilize glycerine or oils which are normally fluid at room temperatures, the most suitable container is a 250 cc. Erlenmeyer flask made of pyrex glass. About 1-1½ ounces are poured into the flask, and the mouth plugged with cotton wool. Sterilize for two hours after the hot-air oven registers 160°C.

Petroleum (*Vaseline*) *Gauze.*—A frequent fault is to prepare too large a quantity, with an excess of petroleum jelly, and to attempt to sterilize the mass by inadequate exposure.

A satisfactory technique is to use a catheter tray measuring about 8 inches by 2½ inches and 1¼ inches. About twenty strips of gauze, or bandage gauze, measuring 7 inches by 2 inches are cut and placed in the tray. Four ounces of petroleum jelly, rendered fluid by heating, are then poured over the gauze. This forms a layer about half an inch in depth with a thin top coating of petroleum jelly. Place in the hot air oven and sterilize for two and a half hours after the oven temperature reaches 160°C. This temperature should not be exceeded, otherwise charring of the top layers of gauze may occur. For instance, a temperature of 171°C produces some discolouration.

Sterilization of Dental Instruments.

There is general agreement that sterilization of the handpiece of dental equipment is a difficult process. It is almost impossible to keep a handpiece clean, much less aseptic.

Boiling water is widely used, and is reasonably effective, if the instrument is mechanically clean when immersed and if 2% sodium carbonate is added to the water. The disadvantage of water is that it promotes rust, and may ruin a keen cutting edge. Mirrors, too, frequently lose lustre after repeated boiling.

If an autoclave is not available or is unsuitable, sterilization in oil is satisfactory. Special oil for this purpose can be purchased. Instruments should be thoroughly degreased in a detergent mixture, such as an organic detergent or equal parts of carbon tetrachloride and liquid paraffin, and then immersed in an oil sterilizer maintained at 320°F (160°C) for 2 hours, or, alternatively, placed in oil in a hot air oven for 2 hours.

Disinfection of dental instruments may be attained by immersion in oil at 250°-266°F for 5 minutes after thorough cleaning. This will kill all vegetative organisms.

Instruments with parts made of rubber or of low melting point plastics should not be placed in the oil sterilizer.

Flaming.

It is not unusual to see instruments such as forceps, scalpels and scissors dipped into alcohol and then held over a flame to light the alcohol. When the alcohol is vapourised the instrument is then used for minor surgery. This is spectacular but quite inefficient because, when the alcohol vapourizes, the heat of evaporation is removed, leaving a cool zone just above the surface of the instrument. It is the alcohol vapour which burns, not the liquid alcohol, which remains cool. If the instrument is felt after the flames have died down, it is frequently found to be barely warm.

On the other hand, holding the dry instrument in a flame until it is very hot is effective but frequently the instrument is ruined. This is only recommended for such instruments as platinum needles or glass rods.

Oil Sterilizers.

Instead of water, oil can be substituted in the average instrument sterilizer. A special grade of oil is required, and the temperature is maintained at 160°C for 2 hours, because oil is anhydrous and longer time is required to destroy spores in oil than in water.

Oil sterilizers are quite satisfactory, but they are foul smelling and messy. Furthermore, the risks of fire and scalding are always present.

The Pressure Cooker as a Sterilizer.

The modern pressure cooker is a single wall chamber in which steam is held under pressure. As a sterilizer, it has several theoretical faults. For instance, the air escape valve is at the top of the chamber, though air is heavier than steam, and air evacuation may therefore be impaired. Secondly, the gauges are frequently inaccurate—indeed, it would be better to discard the gauge and substitute a mercury thermometer. Thirdly, there is no drying mechanism—hence all items emerge wet.

In spite of these disadvantages, the pressure cooker is an extremely useful sterilizer in emergency. Several brands available in Australia were tested as detailed below.

Experiment 1.—Benzoic acid—methylene blue tubes were introduced, one or more to each cooker. To ensure that all the air should be expelled by the steam from the boiling water, more water than the amount prescribed for cooking was introduced. Free exit for steam and air was provided by removing the weight or opening the lever on the exit tube for a period of five minutes.

The weight was then replaced or the lever turned, and a steam-air mixture was allowed to escape for a further five minutes. Heat was turned off, and the cooker opened. In every cooker tested, the benzoic acid was found to have melted, indicating that a temperature of 120°C had been reached within ten minutes of commencing heating.

Experiment 2.—The procedure used by the housewife was followed. The prescribed quantity of water (about half a cupful) was used and the weights used from the outset. After six minutes air-steam mixture was issuing rapidly, and this was allowed to continue for a further four minutes, when heat was turned off. Benzoic acid had melted, indicating that an effective sterilizing temperature had been reached. Other observations showed that if heat is turned down at this stage, as directed in the instruction manual, the cooker will maintain a temperature of 120°C as long as the water lasts.

If benzoic acid tubes are available, it is easy to establish whether a given cooker will attain complete sterilization of articles such as syringes, instruments, and small packages of dressings, provided these are thoroughly cleaned before sterilization. Sterilization should continue for 15-20 minutes after the temperature reaches 120°C, and it may be necessary to add up to 1½ cupfuls of water to the cooker to prevent it boiling dry during this period.

Syringes should be disassembled before being sterilized, and care should be taken to see that only syringes with high melting point cements are placed in the cooker. Syringes and small instruments can be wrapped in cloth, or placed in a perforated aluminium tray. When removed, they should be placed on a sterile dry towel.

Dressings (such as lint, bandages and cotton wool) can obviously be sterilized in a pressure cooker, but packages should be small (not over about 48 cubic inches capacity). When removed they will be wet but may be dried in a domestic oven set at a temperature which will not cause charring.

Small amounts of water, saline, &c., can also be safely sterilized in a pressure cooker.

It is more satisfactory to purchase a cooker which has no pressure gauge, as these are liable to develop faults. Properly used the cooker is a convenient sterilizer for wards and surgeries.

Suggested times for sterilization of various items are given below:—

(1) *Syringes, Needles.*—For twenty minutes after the safety valve starts to blow.

(2) *Rubber Gloves, Small Lengths of Tubing.*—For fifteen minutes after the safety valve starts.

(3) *Bundles of Cotton Wool Swabs.*—Not more than 8 oz. dry weight. For thirty minutes after the safety valve starts to blow. On removal from the cooker, the bundle will weigh 1 lb. 8 ozs. and must be dried in an oven in a pyrex dish. It is convenient to leave these packages overnight in a cooling oven.

CHAPTER 8.

CHEMICAL DISINFECTION.

As indicated in Chapter 2 the words ''sterilize'' and ''disinfect'' are commonly regarded as synonymous terms, but this is not strictly correct. In fact, quite a number of terms are used to describe the process of killing bacteria by chemical action —for instance, germicide, disinfectant, antiseptic, bactericide are regarded largely as interchangeable. Some of these have no concise meaning, but the following definitions may help:—

A *bactericide* kills bacteria, but if the substance merely prevents bacteria from growing, it is said to be *bacteriostatic.*

A *disinfectant* destroys infectious bacteria, other than spores, and this action is called *disinfection.* The word was coined before spores were known to exist.

A *germicide* kills germs.

An *antiseptic* is a substance which will inhibit the growth of bacteria. In other words, it is essentially bacteriostatic.

It can be seen that the distinction between these terms is vague, and it seems desirable to call chemical substances with a lethal action on bacteria by a word such as ''disinfectant'' or ''germicide.''

A *sterilizing agent,* on the other hand, should destroy all forms of bacteria; and few, if any, chemical agents possess this property in the concentrations commonly used. The words ''sterilization,'' ''sterilizer,'' and ''sterilize'' are loosely used—for instance, the cabinet in a hairdressing shop is frequently called a ''sterilizer'' and the instrument for disinfecting instruments by boiling is termed a ''sterilizer'' also, whereas boiling water alone may not sterilize. No matter what the common usage may be, in technical literature it is essential to use the words ''sterilize,'' ''sterilization'' and ''sterilizer'' strictly according to their dictionary definitions.

Limitations of Disinfectants.

It is important to remember that no disinfectant when used in concentrations tolerable to human tissues will cause instant death of the bacteria which it contacts. It is true, however, that a concentrated solution will kill bacteria more quickly than a weak solution of the same disinfectant, but all disinfectants require some time to exert their lethal effect. The time a disinfectant is allowed to act plus the concentration used are the most important factors in disinfection.

The number of disinfectants used in medicine is very large, and certain of these are selected for their value in acting efficiently in the presence of organic matter such as blood, pus or mucus. The intensity and speed with which a disinfectant kills bacteria can be measured in the laboratory, but these tests sometimes give misleading results when the disinfectant is used in the presence of living tissues. Likewise, some chemicals (e.g., acriflavine) have an enhanced action in the presence of organic matter, whilst others (e.g., mercuric chloride) are rendered practically inert.

Some of the factors which influence the action of a disinfectant are given below:—

(1) *Concentration.*—A weak solution is usually less effective than a strong solution of the same disinfectant. A notable exception is ethyl alcohol; 70-80% solutions in water being more bactericidal than absolute alcohol. The concentration of a disinfectant is generally limited by the tolerance of the tissues to which it is applied, but strong solutions of irritant disinfectants such as phenol and cresol can be used for disinfection of sputum, faeces and other bodily discharges where penetration is required and where tissue irritation is not involved.

(2) *Time.*—Very few disinfectants kill organisms at the moment of contact. In the concentrations used in medicine, most disinfectants take time to kill which may vary from seconds to hours. When a nurse is seen to swab a patient's skin with methylated spirits or ether and make an injection almost immediately, it indicates that she has forgotten, or has not been taught, this important factor of time. A few seconds at least should elapse before making the injection.

(3) *Type of Organism.*—Some organisms are readily killed; others, such as *Pseudomonas pyocyanea,* are more resistant to the action of disinfectants, whilst bacterial spores are extremely difficult to kill with chemicals.

(4) *Temperature.*—Most disinfectants are more active as the temperature increases.

(5) *Presence of Organic Matter.*—Blood, pus, faeces, wound debris, mucus and other heavy secretions markedly impair the action of most disinfectants.

Disinfectants are often used wastefully in hospitals with little regard to their cost and their probable action. Application of disinfectants to floors, passages, cupboards, and sinks is rarely justified. Hot water, soap and soda will be more effective and less costly.

PROPERTIES OF SOME DISINFECTANTS.

(1) *Alcohol.*—Ethyl alcohol is only a weak disinfectant but it is inexpensive and has valuable wetting properties. In addition it is miscible with water; in fact, the most powerful germicidal effect is obtained with 70-75% (V/V) alcohol in water, especially if friction is applied to the skin with gauze or cotton wool to remove epithelial scales. Rubbing of the hands or arms with a piece of gauze for three minutes while immersed in 70-75% V/V alcohol will materially reduce the number of bacteria on the skin.

Alcohol is incapable of killing spores—in fact, Bulloch (1928) made cultures from museum specimens that had been immersed in spirits for 39 and 46 years, and obtained sporulating bacteria. Similarly, virulent anthrax spores have been recovered from threads immersed in alcohol for 20 years.

It is therefore clear that the use of alcohol should be confined to disinfection of skin or of articles that are not likely to contain pathogenic spores. Absolute alcohol disinfects less rapidly than alcohol which contains some water. The recommended strength is 70-75% V/V alcohol. This is made by diluting four parts of industrial methylated spirits with not more than one part of water. As alcohol evaporates more rapidly than water, this mixture should be kept in a tightly corked container. If placed in bowls or trays, the solution should be replaced frequently.

Some bacteriologists may object to the use of industrial methylated spirits for skin disinfection, because it has been demonstrated that industrial alcohol as received from the distillery may contain sporulating bacteria. This is true, but it has not been shown that these bacteria are harmful to man, although it is possible that *Clostridium tetani* and perhaps organisms of gas gangrene might gain entrance to alcohol at some stage of its preparation.

In view of the slight risk involved it is not justifiable to advocate filtration or redistillation of all alcohol used in medicine for external application.

(2) *Phenols.*—Phenol, or carbolic acid, was the first disinfectant widely used in surgery. There are many phenol compounds which have a wide use in industry but the official British Pharmacopoeia preparations are Phenol (98% carbolic acid) and Liquefied Phenol (80% carbolic acid).

Phenol and other closely related compounds are not greatly affected by the presence of moderate amounts of organic matter, but are inferior to the cresols in that respect. The germicidal activity is adversely affected by alkalis and by soaps but is increased as the temperature rises. The incorporation of phenol in a soap has been shown to depress its germicidal action.

Phenol is a stable compound which does not deteriorate, and it will kill most pathogenic vegetative bacteria. Phenolic disinfectants are cheaper than cresol compounds. The disadvantages of phenol are that it is extremely toxic, it is irritant when applied in germicidal concentrations, it is relatively insoluble in water, and it produces local anaesthesia when applied to a skin surface. In addition, its odour is disliked by many people.

(3) *Cresols.*—As practical disinfectants, cresols are more valuable than phenols. There are three cresols—ortho, para, and meta cresol. They are only moderately soluble in water (1: 50), but possess the quality of forming an emulsion with soaps and alkali.

Most proprietary disinfectants are varying mixtures of cresols in soap or alkali, and their germicidal activity varies enormously. The British Pharmacopoeia preparation of cresol is Solution of Cresol with Soap, frequently called Lysol. It contains 50% of cresol.

Cresol disinfectants kill most vegetative organisms in low dilution (1:100-1:300), but will not destroy spores. They are more expensive than phenolic disinfectants but are probably the disinfectants of choice against *M. tuberculosis,* because they act readily in the presence of organic matter such as sputum and faeces. They are of reasonably low toxicity, keep well, and the soapy solutions with their strong odour make them suitable for adding to water.

Less purified preparations are made from coal tar. They contain cresols and phenols, and are either dark or light in colour. Germicidal activity of commercial preparations varies considerably, and hospitals should purchase a reliable brand with a high Rideal Walker coefficient.

(4) *Iodine.*—Iodine in solution, next to alcohol, is the most widely used disinfectant and over many years its germicidal activity has been confirmed. It has a remarkably uniform action against a wide range of micro-organisms, and when applied to the skin its action persists for several hours. In the usual concentrations it will certainly destroy all non-sporulating bacteria which it contacts. However, iodine is irritant to tissues, it may cause dermatitis, and it stains badly. On sensitive skins, the risk of dermatitis is greatly diminished, if, after application, the iodine is removed with 75% alcohol.

There are two tinctures of iodine listed in the British Pharmacopoeia of 1948—these are Strong Solution of Iodine (containing 10% of iodine, and 6% of potassium iodide in 81% alcohol) and Weak Solution of Iodine (containing 2·5% of metallic iodine and 2·5% of potassium iodide in 81% alcohol). The stronger solution is too irritant for routine use and the weak solution is sufficiently germicidal for most purposes. Even 1% solution of iodine is satisfactory for skin disinfection.

Iodine is irritant to mucous membranes and tends to concentrate at the margins of the swabbed area. If iodine in glycerine is used (e.g., iodine 1%, potassium iodide 2% in glycerine), this preparation is tolerated better by mucous surfaces.

(5) *Mercury and Mercurials.*—Ever since 1881, when Koch published a monograph extolling the virtues of mercuric chloride as a disinfectant, mercurial compounds have found favour in hospitals. The advent of proprietary organic mercurial compounds, such as Metaphen, Merthiolate and Mercurochrome, has further

popularized this type of disinfectant, in spite of the fact that its defects are well known. In brief, all mercury compounds have a marked and prolonged bacteriostatic action. This property has led to many undeserved tributes to their efficiency. Almost all mercurials have much less activity in contact with organic matter. They act by coating the bacterial cell with a layer of mercury ions, but when this coating is removed by activated charcoal or by the transfer of the ions to tissue cells, the organism is frequently found to be capable of growth. None of the mercury compounds is sporicidal.

Compounds such as mercury oxycyanide, sodium ethyl mercuric thio-salicylate (Merthiolate) and phenyl mercuric nitrate have limited use in the disinfection of certain instruments and as preservatives of biological products and therapeutic solutions.

(6) *Chlorine Compounds.*—Chlorine and its compounds are now the most widely used of all chemical disinfectants, particularly in the disinfection of water and sewage. The most remarkable characteristic of chlorine is the great dilution at which it exerts germicidal action. The germicidal effect is due to a combination of oxidation and chlorine replacement within the bacterial cell. Surgical Solution of Chlorinated Soda (Dakin's solution) is neutral and will dissolve necrotic tissue, but it macerates and irritates the skin, tends to devitalise tissue, and has little hospital use.

(7) *Formaldehyde.*—Formaldehyde is a gas, but Solution of Formaldehyde B.P. (or formalin) contains 37-41% formaldehyde in water, and is the solution commonly used. There is great variation in the reported germicidal activity of formaldehyde, because it is bacteriostatic in high dilutions and because its activity is markedly enhanced by increasing temperature and humidity. For instance, dry formaldehyde gas has little germicidal effect but if it is moistened and warmed it is actively germicidal though it has poor powers of penetration. Formaldehyde has a powerful deodorant action and its germicidal activity is not significantly impaired by mixture with organic matter—as occurs with so many other disinfectants.

In suitable concentrations, solutions of formalin will kill spores, especially if they are not covered by a thick layer of hardened organic matter, and this property renders formalin almost unique amongst disinfectants.

For this reason, formalin solution has a use in surgery particularly for the sterilization of surgical equipment, such as gum elastic catheters and cystoscopes, that may be damaged by exposure to heat. It may also be used for the sterile storage of instruments such as scalpel blades. It should be remembered, however, that formalin is irritant to tissues, and any instrument immersed in formalin must be rinsed thoroughly in sterile water or saline before being used.

Formulae for suitable solutions for sterilization of instruments are given on page 85.

(8) *Quaternary Ammonium Compounds.*—In recent years, a large number of quaternary ammonium compounds have been produced, many for specific purposes as detergents and cleaners, and some of these have marked disinfectant properties. Only a few on the Australian market have been tested for germicidal activity but the future is sure to see many such compounds claiming to be disinfectants.

Two quaternary ammonium compounds marketed in Australia as disinfectants are "Zephiran" and "Cetrimide" B.P.C.

"Zephiran," is a mixture of high molecular alkyl dimethyl benzyl ammonium chloride, and is a metal free, amber-coloured solid, usually sold as a 10% solution.

"Cetrimide" (B.P.C.) is cetyltrimethyl ammonium bromide. It is sold as a powder or solution.

Neither compound will destroy spores with certainty, and both are bacteriostatic in high dilutions, due partly to the formation of a film under which bacteria may survive, and partly to clumping of bacteria so that the compound cannot reach bacteria centrally placed within the clump. Because of this, it is difficult to determine the bactericidal activity of Zephiran or Cetrimide, but tests indicate that both are at least ten times as efficient as phenol against organisms such as *Staphylococcus aureus, Streptococcus faecalis, Escherichia coli,* and *Pseudomonas pyocyanea,* which are commonly found on wounds or on human skin. In addition, both compounds have useful detergent properties. They are non-irritant.

Although these quaternary ammonium compounds are useful disinfectants, their activity is markedly reduced by organic matter such as blood or pus. In addition, they cause rusting of instruments, unless sodium nitrite is added to the solution. A few drops of methylated spirits will diminish a tendency to frothing, but it should be remembered that they are incompatible with soap. If soap is used on the skin it should be washed off before the quaternary ammonium compound is applied.

Finally, if used for skin preparation, a 1% solution in 75% alcohol is recommended for greater safety. As a general skin disinfectant, however, Gardner has shown that quaternary ammonium compounds are inferior to weak solution of iodine.

On the other hand, Zephiran is non-irritant and is pleasant to use. It is highly efficient in low concentrations, but its limitations should be kept in mind.

(9) *Soap.*—The germicidal activity of soap solutions does not properly indicate the great value of soap and water in skin hygiene, for in practice bacteria are removed both in the froth and in the rinse water. Soap is only feebly bactericidal, and organisms vary greatly in their resistance to it, but the combination of soap and water with the mechanical factor of friction removes many organisms from skin.

Soaps containing substances such as phenol or potassium mercuric iodide are not more efficient than ordinary household soap. Surgical soaps containing hexachlorophene are likewise not recommended at present.

The alkalinity of most soap solutions is important only when the solution is heated. For instance, prolonged boiling in soapy water combined with agitation or friction, as in the usual laundry process, will produce almost complete sterility of the articles treated in this way. The same effect would not be obtained by boiling the same articles in water.

CHEMICAL DISINFECTION OF INSTRUMENTS.

Chemical disinfection is often termed "cold sterilization" but the term is misleading.

The ideal chemical disinfectant should kill any organism (including spore-bearing bacteria) that may contaminate an instrument; it should not cause corrosion or deterioration; it should be able to penetrate beneath films of organic matter or grease that are frequently present on instruments; and it should leave no toxic or irritant residue upon the instrument.

No chemical possesses these qualities. Vegetative organisms can be readily destroyed in 30 minutes, even if shielded by a film of dried organic matter, and if vegetative organisms were the only ones encountered on instruments, chemical disinfection would not only be convenient but would be highly satisfactory. Bacterial spores, however, are extremely resistant to chemical disinfectants and the present consensus of opinion on chemical disinfection is—

(i.) That its use should be limited to those instruments which cannot be sterilized by heat;

(ii.) That the instrument should be thoroughly cleaned and then dried before being immersed in the disinfectant solution for a minimum period of 18 hours.

(iii.) That most chemical disinfectants will not kill spores, and therefore the term "sterilization" or "cold sterilization" should not be applied to the process.

Cutting Edge Instruments.—All cutting edge instruments are best sterilized by hot air or by autoclaving as described in Chapter 5. Where these are not available, however, immersion of the cleaned instrument for 18 hours in one of the following solutions is recommended:—

A. *Liquor Boracis et Formaldehydi* (B.P.C.)

Borax	15 G.
Solution of Formaldehyde (B.P.)	25 ml.
Phenol	4 G.
Distilled water	to 1000 cc.

B. *Formaldehyde—Alcohol Solution.*

Solution of Formaldehyde	130 cc.
Potassium nitrite	0·15 G.
Sodium hydroxide	0·012 G.
Ethyl alcohol (95%)	to 1000 cc.

The instrument should be thoroughly rinsed with sterile water before being used.

Telescopic Instruments (Cystoscopes, Thoracoscopes).—These instruments frequently contain cements which may be attacked by chemicals. In addition, alkaline solutions may score and pit the surface of the lens. Modern telescopic instruments with heat resistant cements can be safely sterilized by autoclaving, but few are at present available. Those which cannot be heat sterilized are best immersed in borax-formalin solution or they may be placed in a formalin vapourizer for 18-24 hours.

A satisfactory formalin vapourizer may be constructed from a large pressure cooker, if the lid is fitted with a nipple and stopcock. Ten to twenty mils of formalin are placed at the bottom of the cooker, and the instrument is placed above this on a perforated plate. The lid is closed, and a 5 inch-10 inch vacuum is applied from an air pump or from a water pump through the nipple. The stopcock is closed, and the heater is warmed to about 100°F for 30-60 minutes. The vacuum enables the vapour to penetrate quickly, and the heat produces the necessary humidity to enhance the germicidal effect of formaldehyde. This is a difficult procedure for the average hospital.

Rubber and Plastic Goods.—Most goods are best sterilized by moist heat, but where an autoclave is not available, fairly satisfactory disinfection can be obtained by immersing them for several hours in alkaline formalin solution after they are thoroughly cleaned.

The formula for alkaline formalin solution is:—

Solution of Formaldehyde (B.P.) ..	135 cc.
Sodium hydroxide	10 G.
Distilled water	to 1000 cc.

Many plastics must be disinfected by chemicals, because they do not resist heat, but a suitable disinfectant will vary according to the particular plastic used.

Shellac is a constituent of several types of catheter. It is destroyed by heat, and dissolved by many solvents, including alcohol. Gum elastic catheters are therefore best disinfected by immersion in aqueous solutions such as borax formalin or alkaline formalin, and afterwards rinsed thoroughly in sterile water. Formaldehyde vapour is also satisfactory.

Nail Brushes.—Brushes containing synthetic or vegetable fibre can be sterilized by moist heat. Brushes containing animal fibre, such as hog bristles, should be disinfected in 0·5% aqueous solution of iodine, as heat causes the fibres to curl and crack. There is no need to purchase brushes made with animal fibre.

DISINFECTION OF THE SKIN.

A. *Rapid Disinfection.*—For rapid disinfection of the skin—e.g., prior to injection or minor operative procedures—the most satisfactory solution is 2% iodine in 70% V/V alcohol. This is rubbed in for about 15 seconds and allowed to dry.

Seventy to seventy-five per cent (70-75%) alcohol (V/V) is fairly effective in 5 minutes, as is 1-1000 aqueous solution of Zephiran if allowed to act for 1½-2 minutes, but both are inferior to iodine.

B. *Pre-Operative Disinfection.*—Although the majority of skin bacteria are non-pathogenic, in certain situations (e.g., perineum, groin, hands), pathogenic bacteria may be found. Pathogenic bacteria are also found in increased numbers if the patient has a nasal infection or a skin infection. Most organisms live on the outer layers of the skin, and the majority can be removed by friction and the application of a surface disinfectant; but they are difficult to remove from finger nails and creases of the hands.

In the use of any skin disinfectant the following basic facts must be remembered:—

(1) It is virtually impossible to sterilize the skin.

(2) Disinfection depends on the concentration of the disinfectant and the time during which it is allowed to act. No disinfectant acts at once.

(3) Rubbing the skin whilst applying the disinfectant will bring more bacteria into contact with the solution.

Full details of skin disinfection are given in Chapter 9.

Ampoules.

Tubes (e.g., those containing gut) and ampoules for use in the operating theatre should be disinfected by immersion in a coloured solution of Zephiran 1-100, in alcohol 70%, or in a coloured solution of formaldehyde-alcohol, so that if there is a leak through the glass the leaky container can be readily detected. A coloured solution of Zephiran is obtainable and a suitable dye to add to formaldehyde-alcohol is 0·05% Erythrosine.

It is essential that ampoules and tubes selected for this treatment should have etched labels. Paper labels become detached too easily.

Clinical Thermometers.

It is not considered that clinical thermometers are frequently involved in transferring infection, and spore-bearing organisms in this case are not important.

Provided the thermometers are cleaned periodically of incrustation such as dried mucus, storage in 70% V/V alcohol or 1:1000 zephiran (aqueous) will kill pathogenic vegetative organisms. Alternatively, borax formalin solution can be used, if the thermometer is rinsed in water before use.

Rectal thermometers are a different problem. After each use, the thermometer should be thoroughly cleaned before storing in 5% lysol or in borax-formalin solution. The thermometer must be washed well in water before it is used again. Where temperatures are taken rectally, as in children's wards, each patient should have a separate thermometer, as cross infection with dysenteric organisms has occurred through using one thermometer for several patients.

Disinfection of Sputum Mugs.

Disposable waxed paper containers are ideal, as they can be incinerated together with the sputum. As these are not generally available, however, it is necessary to empty the sputum into some container where it may be disposed of later. The sputum mug is then boiled for 10 minutes in water containing 2% sodium carbonate. When removed and dry, one ounce of 10% lysol or other cresolic disinfectant is added to each sputum mug.

CHAPTER 9.

HYGIENE IN THE OPERATING THEATRE.

When infection occurs in what was expected to be a clean operation wound, every step of the supposedly sterile technique must be carefully scrutinized to determine, if possible, where the bacteria came from. They might come from the materials entering the wound, as, for example, the gauze packs supposedly sterilized by moist heat, or the knife blades and sharp instruments supposedly sterilized by soaking in chemical solutions, or from the catgut supposedly sterilized by heating, or from the water and saline used during the operation supposedly sterilized in large tanks. They might come from the dust particles in the air which dropped upon the sterile field during the course of the operation. They might come from the skin of the patient supposedly sterilized by chemical antiseptics, or from the deep tissues, or from the blood of the patient. They might come from the nose or throat of the operator or his assistants. They might come from the hands of the operators supposedly sterilized by the process of scrubbing with soap and water and soaking in antiseptics before putting on gowns or gloves. Or they might come from the supposedly sterilized gloves, or from the powder used to facilitate their application.

The necessary means by which sterilization can be effected by autoclaving and by boiling have been considered in previous chapters, but the other possible sources of contamination now need examination.

Skin of the Patient.

Though the weakness of chemical means of sterilization has already been stressed, it is manifestly impossible here to replace it with heating methods. The problem becomes rather to bring the patient to the operating theatre with the skin as clean as possible, to do what seems best to sterilize or at least to disinfect the operative region, and then to wall off the wound from the remainder of the skin surface.

Although the majority of the skin bacteria are non-pathogenic, in certain situations (e.g., perineum, groins, hands) pathogenic bacteria can be found. They are also found in increased numbers if the patient has a nasal infection or a skin infection. Most organisms live on the outer layers of the skin, and the majority can be removed by friction and by the application of a surface disinfectant.

All ward clothing, such as pyjamas and blankets, must be suspected of harbouring pathogenic organisms such as haemolytic streptococci.

Before a patient is brought to the operating theatre, he should be socially clean in the sense that he has been thoroughly bathed, and any particular sites of dirt retention, such as the umbilicus, should have received extra attention.

If shaving of the operative site is necessary, it must never be done longer than six hours prior to operation. Abrasions caused by the razor are apt to become infected, and there is abundant evidence that six hours represents the maximum period during which the infecting agent might be mechanically or chemically removed. After this time, it becomes an infected wound and quite unable to be freed from infection.

Though ward pyjamas and blankets may serve as covering as far as the ante-room of the operating theatre, it is essential there that the blanket should be replaced by a sterile covering of cotton or flannelette, and it is desirable that ward pyjamas should be similarly replaced.

The actual disinfecting procedure on the operative field should only be done in the operating theatre just prior to the commencement of the operation. This procedure should have the following objectives:—

(1) Disinfection of skin surface.
(2) Removal of sebaceous plugs from sweat ducts, etc., to allow penetration of the antiseptic.
(3) Hardening of the skin surface to produce a temporary occlusion of skin ducts.

While the removal of sebaceous material can best be effected by fat-solvents and mechanical friction, hardening of the skin needs the use of alcohol.

A common and rational method of skin preparation embodies:—

(*a*) Scrubbing the skin vigorously with a swab soaked in ether or a petroleum product (such as white spirit, benzol, &c.). This has very little antiseptic value, but is a good fat-solvent.

(*b*) Scrubbing the skin with 70% alcohol (antiseptic and hardening value).

(*c*) Scrubbing in a suitable antiseptic.

The efficacy of the antiseptic application depends on its nature, its concentration, and the time it is allowed to act. No antiseptic has shown any advantage over 2% iodine in 70% alcohol solution, rubbed in vigorously for at least 30 seconds. After the iodine has dried, most of it can be removed with 70% alcohol. This will decrease sensitivity reactions.

For those patients whose skins will not tolerate iodine, 70% alcoholic solutions of 1-100 quaternary ammonium compounds (such as Zephiran, Cetrimide) or Surgical Dettol may be used. There is a distinct advantage in a coloured solution, since the extent of the disinfected area is clearly defined, and this should always extend at least six inches in all directions beyond the greatest possible extent of the surgical field.

Since the skin secretions will certainly wash out bacteria from the ducts during the course of an operation, it is best to regard the sterility as only momentary, and as soon as the skin incision is made, impermeable towels—either many layers of dry gauze, or better, sheet rubber—should be securely clipped to the skin edges, and cover all the exposed skin.

The bacteria contained in the deep ducts and glands may again become of importance during the skin sewing up. If a continuous suture is used the needle may pick up organisms and distribute them all along the suture line. A counsel of perfection, often seen in America, is to use individual stitches on separate needles, for each interrupted skin suture.

It should need no stressing that sterile towels should be applied to the unprepared areas of the body after, not before, the skin preparation, and likewise that no palpation of the part should be performed with the sterile gloved hand, except through a sterile sheet.

The Hands of the Operators.

Doctors and nurses frequently contaminate their hands with purulent discharges from the wounds of patients, or when changing their dressings or handling their bed-clothes. If the doctor or nurse then proceeds to the operating theatre, the possibility of carrying these organisms to the sterile field is a very real one. The scrub-up is the intervening barrier.

It is highly undesirable that the hands should be so infected, and the protection of rubber gloves should be sought whenever infected wounds are being handled. The example of Theodor Kocher, who wore gloves all his life except when operating, was at least rational, even if extreme.

Disinfection of the hands is based on thorough scrubbing with a nail brush in soap and warm water. In this procedure, the time is not so important as the vigour with which the superficial layers of skin and its crevices and grooves are scrubbed. The nails must be short and clean, and a technique should be developed whereby every area of the hand and forearm is scrubbed several times.

Countless organisms are removed in this process, and doubtless, the longer it is continued, the more complete the disinfection. But since such vigorous scrubbing does some damage to the skin, there must be an optimum time, which is probably about three minutes; with some of the new soapless detergents, even a less time may well be adequate.

After such mechanical cleansing, the skin is particularly suited to the action of antiseptics, and in theory those that are best for the patient's skin would be best for the surgeon's hands. The necessity of frequent repetition of applications makes such irritants as iodine unsuitable; but acceptable substitutes are 75% alcohol solution (particularly valuable for its hardening effect), or 1-100 aqueous solution of a quaternary ammonium compound. The solution should be applied for at least two minutes, preferably rubbed in with a sterile gauze pad, and the hands should then be dried on a sterile towel.

The Problem of Glove Powder.

Though the use of dry gloves allows a more sensitive surgical touch, and avoids the macerating effect of moisture, the necessity of using a powder to facilitate their application makes several problems. Not only is talc subject to contamination with pathogenic organisms, and difficult to sterilize, but also there is ample evidence that it acts in the abdomen as a gross irritant, causing granulomatous reactions with adhesion formation.

If talc is used to assist in putting on gloves, as much as possible should be emptied from the fingers before applying them and in addition any excess talc should be washed off the outside of the gloves before use.

Certain commercial firms are now making prepared starch powders which are absorbable, and their use is advocated to avoid the possibility of talc irritation.

Since gloves are perforated in a large percentage of all operations, it is well to remember that the wearing of sterile gloves will never replace the necessity for a thorough preparation of the underlying hands.

The Air of the Operating Theatre.

In the early days of antiseptic surgery, Lister believed that organisms dropping from the air played an important role in wound infection, and developed his elaborate carbolic spray apparatus for treating the atmosphere. It later developed that this was one of the relatively minor factors, but as the more major sources of infection were brought under control, this source has become relatively important again.

Even if the fresh air supplied to operating rooms is filtered or sterilized, it will be nullified by the opening of doors, the coming and going of assistants or spectators, the spread of blankets, and the general movement of people connected with the operation. If agar plates are exposed in a theatre where no operation is going on and no one moving in and out, the number of colonies appearing on the plate is only one-tenth of that developing on plates in a room where there is activity during an operation. The moral of this is plain.

(*a*) *Air-conditioning Systems.*—Clean air should enter operating theatres from a source as high above the ground as possible. If there is an air-conditioning system, the air should be pushed in at slight positive pressure rather than exhausted from the theatre. While an exhaust system tends to sweep up dust from the floors, to create unpleasant draughts, and to draw air from unsterile sources into the theatre, a pressure system ensures that the air movement from the theatre is all outwards. The most effective method of removing bacteria from the air is by electro-static precipitation, which removes dust as well. This is a big advance over filtration through oiled screens, glass wool, or particulate filters, which are expensive and require frequent replacement. Air should not recirculate in theatres, owing to the possibility of building up dangerous concentrations of explosive gas.

For hot dry regions, evaporative conditioning systems give good results.

(*b*) *Disinfection by Ultra-violet Light.*—This is being used on an increasing scale for disinfection of air, not only in operating theatres, but in the food and poultry industries.

The spectral band at 2652A (Angstrom units) appears to produce the maximum bactericidal action, and the emission band at 2537A is approximately 75% as effective. However, the use of a lamp producing principally the wave length 2562A is impracticable, and by general consent, the emission line concentrated at 2537A is taken as the standard of ultra-violet radiation in evaluating the germicidal activity of ultra-violet lamps.

Makeshift installations are completely ineffective. In order to kill bacteria a direct hit by ultra-violet radiation of sufficient intensity is required, therefore lights must be properly spaced.

Installation of ultra-violet lamps in theatres should be regarded as a luxury unless all other measures to prevent infection are rigidly observed. More organisms enter a wound on fingers, dressings and instruments and from inefficient masks than from the surrounding air. At present, ultra-violet lamps are not recommended as standard fittings in operating theatres.

(*c*) *Control of Bacteria Entering the Theatre from Clothing, Blankets, and Shoes.*—Theatre staff should discard street clothing or uniform before entering the theatre. Shoes should be removed and replaced by canvas shoes, or else canvas overshoes should be worn. A boiler suit is suitable for surgeons, or else freshly laundered trousers and shirt. Female personnel should discard uniforms, stockings and shoes, and wear freshly laundered gowns, stockings and canvas overshoes.

No ward blankets should ever enter the operating theatre, but should be replaced in an ante-room by clean laundered cotton or flannelette covers. The floors of the operating theatres should be made of impervious material and should never be constructed of wood or other material which allows bacteria to lodge in cracks and grooves. The floor may be cleaned by a vacuum cleaner fitted with a filter on the outlet, or by mopping it with 1% lysol solution. Blood or pus on the floor should be removed by mopping with 10% solution of lysol.

If the theatre floor is covered with linoleum it should be treated periodically with spindle oil at the rate of one pint per twenty square yards, after it has been scrubbed clean. This treatment reduces bacteria but is not suitable for rubber, tiling or concrete.

Shelves, ledges and walls should be wiped clean and then mopped with 1-1000 aqueous solution of a quaternary ammonium compound.

As has been stated earlier, the movement of persons around the operating theatre is highly undesirable.

Much can be done by proper design and organisation to reduce such movement. In particular, traffic between the sterilizing room and the theatre can be greatly diminished by the provision of a window and counter through which instruments, &c., can be passed.

The design of the theatre block should ensure that the theatre need not be used for traffic into sterilizing rooms, or wash-up places.

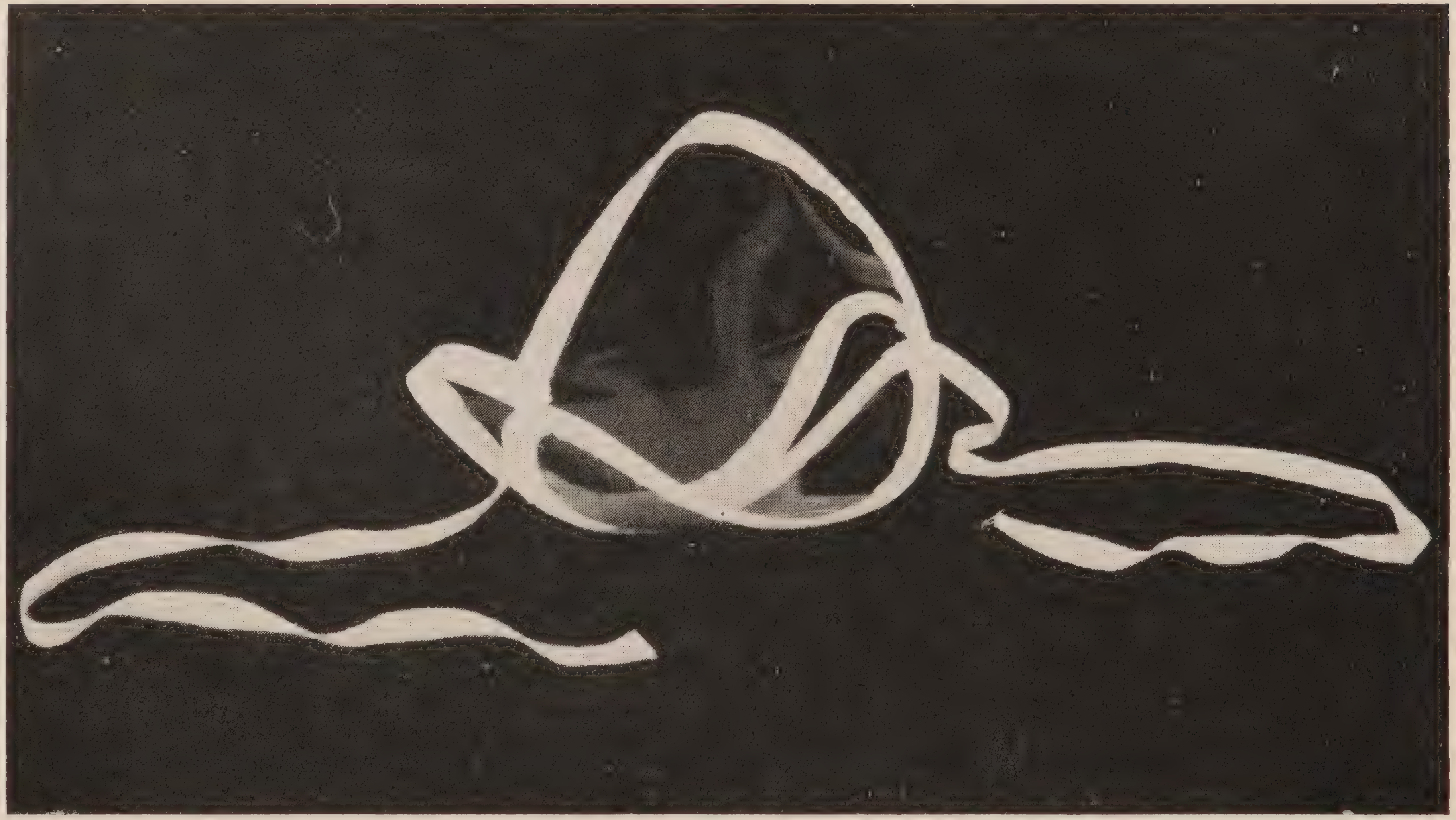

FIGURE 30.

The illustration shows a common type of deflection mask, made of used X-ray film and tape. The object of this type of mask is to deflect the breath away from the operating field through openings in the sides of the mask.

The presence of onlookers on either theatre floor or theatre gallery is highly undesirable, and modern theatre design can arrange for onlookers to be completely separated by glass partitions from the theatre itself. Theatre lighting should be so designed that the frequent leaning of non-sterile personnel over the patient to adjust the light is obviated.

The use of an electric fan in the theatre stirs up every particle of dirt in the room, and is a most effective method of spreading infection.

Infection from Nose and Throat of Operating Theatre Personnel.

There is little doubt that most epidemics of wound infection can be traced to the nose and throat of members of the operating team. Many investigations have shown that about 33 per cent. of operating room staff harbour haemolytic streptococci or staphylococci in their throats, while many individuals carry them in the nose as well. During times of respiratory infection up to 60% of staff are carriers. It is obvious, then, that the clean operative wound must be protected from such infection.

An unmasked person breathing quietly expels only a few bacteria. But talking, coughing, laughing, or forced expiration causes a large number of bacteria to be released, chiefly in droplets of saliva or mucus.

Lack of masking of theatre personnel could only be justified in the certainty that no member will speak or cough. Since this is quite impracticable, adequate masking must be enforced, without exception, on every member of the theatre personnel.

What constitutes adequate masking?

This may be defined as the protection of the operative wound, by means of impermeable masks, from organisms which may be projected into it from either the mouth or nose of the operator or any member of the operating team.

There is little doubt that the best masks are truly impermeable, in the sense that celluloid, or cellophane, or metal is incorporated in the mask, so that there can be no direct projection of bacteria-laden air on to the operative field. Rather the breath is deflected with greatly diminished velocity into the general theatre air, when only a minute proportion of organisms should settle on the operative site. Many good deflection masks are available, and Figure 30 shows one in wide use in Queensland. This is made from used x-ray film.

Certain filtration masks are relatively efficient. Their fine mesh catches most of the droplets, which then evaporate. Fine meshed gauze masks consisting of four layers of gauze, with 60-80 strands to the inch, are satisfactory; while more effective still are two masks, one covering the mouth only, and the second completely covering the chin, mouth, and nose. Each mask is secured by four tapes, and if a metal strip is incorporated in the upper border, and moulded to the contour of the nose, there is little trouble with fogging of glasses.

If a member of the operating team is known to have a cold, he should wear two masks, a filtration type being tied underneath a deflection mask.

Neither the patient nor the anaesthetist is exempt from the possibility of spreading air-borne organisms, and the anaesthetist must always be adequately masked, while an anaesthetic screen acts as a deflection mask for the patient.

Infection from within the Tissues of the Patient.

Though contamination of an operation wound by infection from within the patient cannot always be prevented, there are certain principles of treatment which will allow its effect to be minimised.

(*a*) *Local tissue susceptibility.* Even though a wound may become contaminated, its local resistance to infection will depend greatly on the amount of trauma and handling of tissues that has occurred. Extravasation of blood, the use of drains, mass ligation of tissues and the tension upon or strangulation of tissues by sutures, as well as the mechanical effects of local activity, or distension from within (as in abdominal wounds), all play a role by hindering the early stages of repair, or by cutting down the blood supply; and thus favour infection. The surgeon who reduces these factors by clean cutting, absence of rough retraction, meticulous care in avoiding tying off tissues other than bleeding points of vessels, the use of interrupted sutures under gentle tension, and the careful cleaning of blood-clot or other foreign materials from wounds before suture, will obtain a corresponding reward in rapid clean healing.

(*b*) *The factor of suture material.* It has become increasingly obvious over many years, though well recognised by Kocher and Halsted, that wounds sutured with non-absorbable sutures are less likely to become infected than when catgut is employed. In their order of usefulness, as a prophylactic against infection, sutures may be placed in this order: stainless steel alloy wire, silk, cotton, catgut. The suture material used should always be as fine as possible. It would be extremely unusual to need suture material of greater strength than No. 1 catgut or No. O silk. If greater tensile strength is required, it is better to use a double thread of fine material, rather than a single thread of coarser size.

The superiority of a material such as silk over catgut is due to the following reasons:—

Firstly, haemostasis is better, for silk knots become untied less easily than catgut.

Secondly, the cellular and fluid reaction around silk is minimal, while that about catgut is maximal. While silk is almost inert in the tissues, catgut is itself a dead tissue which must be digested.

CHAPTER 10.

SUMMARY OF STERILIZATION METHODS FOR VARIOUS ITEMS.

Item.	Methods recommended, in order of preference.	Remarks.
Bottles, Flasks—		
(*a*) Empty	1. Hot air—60 minutes at 160°C.	Items must be clean and free from grease. Do not open oven till cool.
	2. Autoclave—20 minutes at 120°C.	Must be clean. Lay flasks and bottles on side without corks or plugs
	3. Boil 10 minutes in water containing 2% washing soda	Glass ware should be clean. Soda may attack glass. Invert or place in oven to dry
(*b*) Containing aqueous solutions	1. Autoclave 15–30 minutes at 120°C. according to volume	Relax pressure slowly to prevent bubbling. Remove cork and use cotton wool or gauze plugs
Catheters—		
1. Rubber	1. Autoclave 15 minutes at 120°C.	Lay straight without kinks. Elevate one end of tube
	2. Boil 10 minutes in water containing 2% washing soda	
	3. Soak in alkaline formalin solution for several hours	See Chapter 8 for formula
2. Gum elastic ..	1. Soak in alkaline formalin solution or borax formalin solution for several hours	See Chapter 8 for formula
	2. Formaldehyde vapour if suitable apparatus available	
Cotton goods (theatre bundles)	1. Autoclave for 30 minutes at 120°C.	See Chapter 4 for precautions to be observed
	2. If less than 8oz. bundle, place in pressure cooker for 30 minutes at 120°C.	Bundle must be dried later in oven

SUMMARY OF STERILIZATION METHODS FOR VARIOUS ITEMS—*continued.*

Item.	Methods recommended, in order of preference.	Remarks.
Cystoscopes, Thoracoscopes	1. If lens system set with high melting point cement, autoclave for 10 minutes at 120°C. 2. If lens not set in high melting point cement, immerse in borax formalin solution for several hours 3. Expose to formalin vapour if suitable apparatus available	Do not allow to contact alkaline solutions, which attack glass
Dishes, Basins, Trays, Jugs.	1. Autoclave at 120°C. for 15 minutes 2. Boil for 10 minutes in water containing 2% washing soda	Place in autoclave in such a way that if dish contained water, it would run out. Basins should be stood on side.
Glycerine	1. Hot air oven—2 hours at 160°C.	Limit quantity to 1 oz. in small bottle or flask
Instruments—		
(*a*) Cutting	1. Hot air oven—1 hour at 320°F.	For preparation see Chapter 5.
	2. Autoclave for 15 minutes at 120°C.	
	3. Immerse in borax-formalin solution or in Formaldehyde alcohol solution for 18 hours	For formulae see Chapter 8
	4. Boil for 10 minutes in water containing 2% washing soda	Dulls the edge of the instrument and promotes rust
(*b*) Non-cutting . .	1. Autoclave for 10 minutes at 120°C. if uncovered; for 15 minutes if covered	Instruments should be clean and free from grease
	2. Boil for 10 minutes in water containing 2% washing soda	May tarnish instruments. For precautions see Chapter 5.
	3. Hot air oven—1 hour at 320°F.	
(*c*) Optical	. .	See Cystoscope

SUMMARY OF STERILIZATION METHODS FOR VARIOUS ITEMS—*continued.*

Item.	Methods recommended, in order of preference.	Remarks.
Needles—		
(*a*) Suture	1. Hot air oven—1 hour at 160°C.	Sew into gauze and place in Petri dish
	2. Autoclave for 10–15 minutes at 120°C. with surgical instruments	Sew into gauze
	3. Boil for 10 minutes in water containing 2% washing soda	This treatment causes rusting
	4. Place in alcohol-formalin solution for 18 hours	For formula see Chapter 8
(*b*) Hollow-hypodermic type	1. Hot air oven—2 hours at 160°C.	Place in tubes, or thread through gauze
	2. Autoclave—15–20 minutes at 120°C.	Autoclave with syringes
	3. Pressure cooker—15–20 minutes at 120°C.	Place with syringe
	4. Boil for 10 minutes in water containing 2% washing soda	
Oils, Waxes, Petroleum jelly	Hot air oven—120 minutes at 160°C.	Limit quantity to ¼″ layer (1 oz.) in Petri dish, small flask, or ointment jar
Petroleum (Vaseline) Gauze	Hot air oven—2½ hours at 160°C.	For details, see Chapter 7
Powders—		
(*a*) Talcum .. (*b*) Starch ..	1. Hot air oven—120 minutes at 160°C.	Limit quantity to ¼″ layer in Petri dish, later transfer to sprinkler top cans
	2. Domestic oven—2 hours at 400–500°F.	For details see Chapter 7
	3. Autoclave. Spread thinly on gloves and autoclave for 15 minutes at 120°C.	For details see Chapter 7
Rubber Goods—		
(*a*) Aprons, pads, sheets	1. Autoclave for 15 minutes at 120°C.	Difficult to sterilize even if properly packed
	2. Immerse in borax-formalin solution or in 5% Lysol for 2 hours	Dry with sterile towels
(*b*) Gloves	1. Autoclave for 10–15 minutes at 120°C.	Pack specially. For details see Chapter 4
	2. Boil for 10 minutes in water containing 2% washing soda	Must be kept completoly immersed

SUMMARY OF STERILIZATION METHODS FOR VARIOUS ITEMS—*continued.*

Item.	Methods recommended, in order of preference.	Remarks.
Rubber Goods—*cont'd.*		
(*c*) Rubber Tubing	1. Wrap loosely round cylinder. Autoclave for 20 minutes at 120°C.	Difficult to sterilize. Must be thoroughly clean and free from sulphur and any powder
Suture Material—		
(*a*) Catgut ..	Purchase ready sterilized	If boilable, autoclave tube with instruments. If non-boilable, immerse tubes in coloured solutions of 1–100 Zephiran or formaldehyde-alcohol solution
(*b*) Cotton	Autoclave for 15 minutes at 120°C.	Wind loosely on gauze or on rubber tubing
(*c*) Horsehair ..	Purchase ready sterilized	Immerse tubes as in (**a**) above
(*d*) Kangaroo tendon	Purchase ready sterilized	Immerse tubes as for non-boilable catgut
(*e*) Nylon (braided or monofilament)	Autoclave with instruments for 10–15 minutes at 120°C.	Prepare as loose coils or wrap round metal or glass spool
(*f*) Silk	1. Purchase ready sterilized	Immerse tubes as for non-boilable catgut
	2. If unwaxed in reels, autoclave for 15 minutes at 120°C. If waxed in reels autoclave for 30 minutes at 120°C.	Wind loosely on spools. Do not autoclave more than three times
(*g*) Silkworm Gut ..	Immerse in water and autoclave for 30 minutes at 120°C.	
(*h*) Tantalum and other metals	1. Autoclave with instruments for 10–15 minutes at 120°C.	
	2. Boil for 10 minutes in water containing 2% washing soda	
Syringes..	1. Hot air oven—1 hour at 160°C	If metal plunger type, sterilize unassembled. Do not remove till cool.
	2. Autoclave for 15–20 minutes at 120°C.	Place in tubes or wrap in cloth. All syringes must be clean and barrels matched with pistons
	3. Sterilize by pressure cooker for 20 minutes at 120°C.	Add extra water to cooker. Time exposure from the time the safety valve blows.
	4. Boil 10 minutes in 1% Lysol	Do not wrap. Rinse in sterile water before use
	5. Boil 20 minutes in soft water	
	6. Immerse in 70–75% alcohol	Rinse in sterile water before use

ACKNOWLEDGMENTS.

The Committee is indebted to many authors of articles on sterilization appearing in scientific journals, and is particularly grateful to the American Sterilizer Company, Erie, Pennsylvania, for permission to reproduce illustrations and to quote from its excellent publications including ''A Text Book of Sterilization'' by Weeden B. Underwood, and various issues of ''The Manual of Sterilization, Disinfection and Related Surgical Techniques.''

FURTHER READING.

Those interested in obtaining further details of sterilization techniques are advised to consult—

''The Aseptic Treatment of Wounds,'' by Carl W. Walter. (The Macmillan Company, 1948.)

''Textbook of Sterilization,'' by Weeden B. Underwood. (The American Sterilizer Company, 1941.)

''Sterilization and Disinfection,'' by Ernest C. McCulloch. (Henry Kimpton, 1945.)

''The Sterilization, Use and Care of Syringes,'' by a Committee appointed by the Medical Research Council. (H. M. Stationery Office, London, 1945.)

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THE MEDICAL JOURNAL OF AUSTRALIA
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